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OCTOBER 1953

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Cover—This F9F-6 Cougar, Grumman Aircraft Engineering Corporation's swept-wing successor to the F9F-5 Panther, is powered by a Pratt & Whitney turbojet engine. Its armament is comparable with that of other Navy jet fighters.

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SUBSCRIPTION RATES

Aeronautical Engineering Review: United States and possessions, 1 year, $3.00, single copies, $0.50. Foreign countries including Canada (American Currency Rates), 1 year, $3.50, single copies, $0.50.

Entered as second-class matter at the Post Office, Easton, Pa., April 29, 1942. Acceptance for mailing at a Special Rate of Postage as provided for in the Act of August 24, 1912.

Publication Office: 20th & Northampton Streets, Easton, Pa.

Editorial Office: 2 East 64th Street, New York 21, N.Y. Notices of change of address should be sent to the Institute at least 30 days prior to actual change of address.

Statements and opinions expressed in the Aeronautical Engineering Review are to be understood as individual expressions and not those of the Institute.

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AERONAUTICAL ENGINEERING REVIEW

Vol. 12 OCTOBER, 1953 No. 10

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I.A.S. News Notes

October 1953

WORLD AIR PIONEERS HONORED

International aviation pioneers are being honored at a dinner in Washington, D.C., on October 12, sponsored by the National Aeronautic Association as part of the 50th year of flight celebration. Lieutenant General James H. Doolittle, Chairman of the National Committee to Observe the 50th Anniversary of Powered Flight, is toastmaster, with Admiral Richard E. Byrd presiding. One of the speakers is C. Kolff, of the Netherlands, President of the Federation Aeronautique Internationale, which is celebrating its 48th anniversary on this occasion.

Arrangements have been made by a committee composed of Admiral Byrd as Chairman; Dr. John F. Victory, Executive Secretary, NACA, and NAA Director; Grover Loening, Aeronautical Consultant; and Major Lester D. Gardner, IAS Founder. Walter T. Bonney, Assistant to the Executive Secretary, NACA, is acting as Program Coordinator.

* * * * * * * *

NEW IAS CORPORATE MEMBER

Air Associates, Inc., Teterboro Air Terminal, Teterboro, New Jersey

* * * * * * * *

NECROLOGY

Captain Phillip M. Clinton, USAF, Student Officer, Graduate Aeronautical Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, on July 6.

John C. Marsh, Factory Superintendent, Eastern Rotorcraft Corporation, on July 31.

Rudolph D. Van Dyke, Jr., Aeronautical Research Pilot, Ames Aeronautical Laboratory, NACA, in June.

Charles Wilbur Weaver, Jr., Junior Stress Engineer, Prewitt Aircraft Co., on May 22.

* * * * * * * *

NATIONAL MEETINGS CALENDAR

Dec. 17 Seventeenth Wright Brothers Lecture, U. S. Chamber of Commerce Building Auditorium, Washington, D. C. Glenn L. Martin, Lecturer.

Jan. 25-29 Twenty-Second Annual Meeting and Honors Night Dinner, Hotel Astor, New York.

* * * * * * * *

CALENDAR OF SECTION MEETINGS

Oct. 1--San Diego Section: IAS Building. Technical Meeting, 7:30 p.m. "Variable Area Exit Nozzles" by J. S. Winter and R. G. Laucher, Marquardt Aircraft Company.

Oct. 3--Texas Section: Field trip to Ordnance Aerophysics Laboratory, Daingerfield, Texas.

Oct. 7--Chicago Section: American Airlines, Inc., Midway Airport. Meeting, 7:00 p.m. Tour of facilities, including stewardess school.

Oct. 12--Washington Section: Museum of Natural History Auditorium. Meeting, 8:00 p.m. "Impressions of the SBAC Show and the Joint RAeS-IAS Meeting" by Dr. Hugh L. Dryden, Director, NACA, and Rear Adm. L. B. Richardson, USN (Ret.), Senior Vice President, General Dynamics Corp. Rear Adm. C. M. Bolster, USN, Chief of Naval Research, presiding.

Oct. 15--Los Angeles Section: IAS Building. Social hour, 5:30 p.m.; Dinner, 6:30 p.m.; Meeting, 8:00 p.m. "Design Philosophy for Aircraft Control" with panel discussion by C. Stark Draper, Massachusetts Institute of Technology; Ben O. Howard, Aviation Consultant; A. L. Klein, Douglas Aircraft Company, Inc.; John R. Moore, North American Aviation, Inc.; Simon Ramo, Hughes Aircraft Company; and J. B. Rea, J. B. Rea Company. Introduction of panel members by Harold Luskin, Douglas Aircraft Company, Inc.

Oct. 15--Twin Cities Section: American Legion Club. Social, 6:30 p.m.; Dinner, 6:45 p.m. Speaker, Carl J. Wenzinger, Arnold Engineering Development Center.

Oct. 22--San Francisco Section: Ramor Oaks, Atherton, Calif. Meeting, 8:00 p.m. "Supersonic Aircraft Design" by Harold Luskin, Asst. Supervisor of Aerodynamics for Research, Santa Monica Plant, Douglas Aircraft Co., Inc.

Oct. 22--Texas Section: Location, time, and panel not known at press time. Joint meeting with SAE. Subject: The Farnborough Air Show.

Oct. 29--San Diego Section: IAS Building. Technical Meeting, 7:30 p.m. "Systems Analysis" by Adolph Burstein, Consolidated Vultee Aircraft Corporation.

Nov. 3--Washington Section: Museum of Natural History Auditorium. Time, subject, and speaker not known at press time.

Nov. 12--San Diego Section: IAS Building. Technical meeting, 7:30 p.m. "Ceramic Coatings" by Mr. Long, Solar Aircraft Company.

Nov. 19--Los Angeles Section: IAS Building. Social hour, 5:30 p.m.; Dinner, 6:30 p.m.; Meeting, 8:00 p.m. Annual business meeting with installation of officers. Speaker and subject not known at press time.

* * * * * * * *

IAS News

A Record of People and Events of Interest to Institute Members

Pioneer Manufacturer to Present 1953 Wright Brothers Lecture

Lecture to Be One of the Final Events in Celebration of the Fiftieth Anniversary of Powered Flight

THE SEVENTEENTH WRIGHT BROTHERS LECTURE will be delivered at the U.S. Chamber of Commerce Building Auditorium in Washington, D.C., on December 17, 50 years to the day since the Wright Brothers made their famous flight. The lecturer will be Glenn L. Martin, a Director of The Glenn L. Martin Company. Mr. Martin is an IAS Honorary Fellow, Founder Member, Past-President, and Benefactor; and a Fellow of the Royal Aeronautical Society. Dr. Jerome C. Hunsaker, HFIAS, Professor Emeritus of Aeronautical Engineering, Massachusetts Institute of Technology, will serve as the Lecture Chairman.

Mr. Martin's paper will be concerned with the beginnings of today's aeronautical industry; the pioneers who demonstrated their faith in the future of the "newfangled flying machine" by devoting their lives to aeronautical development; the uses and trends of today's industry; and a prognostication of the future of aviation.

Mr. Martin has been actively engaged in aviation during the past 46 years. It was in 1907 that he built his first glider and in it soared from the hills near his home in Santa Ana, Calif. The next year, he rented an abandoned church building in Santa Ana and, with the help of his mother, the late Minta Martin, constructed a biplane of his own design which was powered by a 30-hp. Eldridge motor. Completed in 1909, it made its first flight in the area of Santa Ana on August 1 of that year with Mr. Martin at the controls.

He had taught himself to fly, and, beginning in 1909 and continuing until the latter part of World War I, he gave flying exhibitions in the United States and Canada. On August 9, 1911, he qualified for Fédération Aéronautique Internationale (F.A.I.) Aviators Certificate No. 56, and, the following year, he received the Aero Club of America's Expert Aviators Certificate No. 2. In 1912, he flew a seaplane of his own design from Newport Bay, Calif. (near Los Angeles) to Catalina Island and back. He was the first pilot to deliver mail and newspapers by plane and the first to drop a baseball into a catcher's mitt by plane. Some of his other aerial stunts included tossing a bouquet into the lap of a May Queen, bombing a sham fort, hunting coyotes, tracking escaped convicts, and picking up a passenger from a boat.

At about the time he made his first power-driven airplane flight in 1909, he sold his automobile business to devote his full time to aircraft manufacturing. That same year, he established one of the first airplane factories in the United States and 2 years later incorporated it as The Glenn L. Martin Company. In 1912, he moved the factory from Santa Ana to Los Angeles where for the next year he built planes for exhibition and sports flying. In 1913, he received his first order from the U.S. Army; this was for Model TT, later adopted by that service for training purposes. For the next 4 years, he produced several new models for the U.S. Army and 24 airplanes for other countries.

Glenn L. Martin.

In 1917, when this country entered World War I, the Martin company merged with the Wright Company, forming the Wright-Martin Corporation, of New York. Later that same year, Mr. Martin withdrew from that corporation and organized The Glenn L. Martin Company, of Cleveland. In January, 1918, he was authorized by the Government to build a few models. The first one, a Martin biplane bomber powered by two 400-hp. Liberty motors, came off the assembly line about 6 months later. The company was able to weather the postwar slump in aircraft production requirements and by 1929 had outgrown its Cleveland facilities. At that time, the entire business was moved to its present location in Middle River, Md., 12 miles from Baltimore.

Between 1929 and the beginning of rearmament for World War II, the Martin company turned out such aircraft as the B-10 twin-engined monoplane bomber and flying boats for transoceanic passenger service. During World War II, the company built the B-26 Marauder, PBM, Mars, Model 167 Maryland, and Model 187 Baltimore. At present, it is producing the P5M-1, B-57A, B-61

Matador, Viking rocket, electronic systems, and weapons systems.

A native of Macksburg, Iowa, Mr. Martin attended Kansas Wesleyan University, which in 1933 conferred upon him an honorary Doctor of Science degree. He received similar degrees from Brown University in 1941, from the University of Omaha in 1945, and from the University of Southern California in 1949. Honorary Doctor of Engineering degrees were granted to him by the University of Maryland in 1929 and Case School of Applied Science in 1945. He has been the recipient of numerous awards, among them being the Robert J. Collier Award for 1932, the Daniel Guggenheim Medal for 1940, and the French Legion of Honor in 1949. In 1931, Mr. Martin delivered the Royal Aeronautical Society's Wilbur Wright Memorial Lecture entitled "The Development of Aircraft Manufacture."

Cooper Precision Products Joins IAS

Cooper Precision Products, manufacturers of aircraft bolts and special cold-headed products, has become a Corporate Member of the Institute of the Aeronautical Sciences. This company is located at 5625 W. Century Blvd., Los Angeles 45.

Cooper Precision Products is an outgrowth of the old San Francisco firm of Cooper Screw Manufacturing Company, which in 1940 opened a branch plant in Los Angeles for the production of threaded fasteners. In 1946, 14 years after that company's initial organization by Harry S. Cooper and his two nephews, Irving and Jack Cooper, Cooper Screw Manufacturing Company was sold, and the senior Mr. Cooper retired from business for reasons of health.

In 1948, at the instigation of his friend and coworker in aircraft fasteners, Col. Howard M. (Cappy) Rix, Harry Cooper came out of retirement. With the assistance of Colonel Rix, Irving Cooper, and Jack Cooper, he organized Cooper Precision Products. The facilities of this new firm have been expanded since that time. As of July 1, 1953, Cooper Precision Products became a wholly owned subsidiary of Standard Pressed Steel Company.

The present officers of Cooper Precision Products are: President, Harry S. Cooper; Vice-President and General Manager, Col. H. M. Rix; Treasurer, Jack Cooper; Secretary, Irving Cooper; and Assistant Secretary-Treasurer, Shirley Jacoby. Miss Jacoby, one of the original management personnel of Cooper Precision Products, had served Harry Cooper for more than 10 years in the old firm.

Flight Safety Course Organized

What is believed to be the first attempt to organize an accident prevention training course at a major civilian university was recently undertaken by the University of Southern California under contract to the U.S. Air Force. This training program, which is of a 6-week duration, is designed for USAF Flying Safety Officers.

The curriculum includes 72 hours of classroom instruction on the basic principles of aeronautical engineering, 140 hours of classroom instruction on other pertinent subjects, 6 hours of laboratory work, and 7 hours of field trips to aircraft manufacturers and test laboratories.

The subjects covered during the 72 hours of aeronautical engineering instruction are: aerodynamics, stability and control, strength of materials, aircraft loadings, aircraft structures, aeroelasticity, and flutter and vibration. The 140 hours of other instruction considers the fields of aircraft accident investigation, accident prevention, aviation physiology, aviation psychology, and educational principles and methods.

U.S.C. proposes to train 320 Flying Safety Officers at 6-week intervals during the next 3 years.

RAeS President-Elect

Sir Sidney Camm, FRAeS, Director and Chief Designer of Hawker Aircraft, Limited, England, has been chosen President-Elect of the Royal Aeronautical Society. Sir Sidney, who is an RAeS Vice-President for 1953–1954, will be installed as the RAeS President at the Society's Annual General Meeting scheduled for May 6, 1954.

Sir Sidney began his aeronautical career in 1914. Nine years later, he joined the Hawker organization and in 1925 was appointed Chief Engineer. In this capacity, he has been responsible for the design of such aircraft as the Hart, Fury, Nimrod, Osprey, Hind, Henley, Hurricane, Typhoon, Tempest, Sea Fury, Sea Hawk, and Hunter. He was elected to Hawker's Board of Directors in 1945.

In 1949, Sir Sidney was awarded the British Gold Medal for Aeronautics. He received his Knighthood in the recent Coronation Honours List.

News of Members

▶ **Lawrence D. Bell** (AM), President and General Manager, Bell Aircraft Corporation, was recently named the representative of the aircraft industry on the Industries Advisory Committee of The Advertising Council.

▶ **Franklin A. Dobson** (AF), Design Specialist, North American Aviation, Inc., is heading a group of California engineers who are developing as a private project a delta-wing convertiplane. The prototype, scheduled for flight testing sometime this year, is expected to have a maximum speed in level flight of 172 m.p.h. and a maximum climb of 1,950 ft. per min. Mr. Dobson has applied for the patents on the design.

Daniel O. Dommasch, AFIAS, became Associate Professor of Aeronautical Engineering at Princeton University on September 1. Consulting and research activities are concerned with this appointment. Professor Dommasch was formerly Chief Engineer of the Test Pilot Training Division, Naval Air Test Center, NAS, Patuxent River, Md.

▶ **Mrs. Gertrude Hill Fila** (M), who has been an Instructor in Mechanical Engineering at Oklahoma Agricultural and Mechanical College, was recently awarded the Amelia Earhart Scholarship for 1953 by Zonta International, an organization of executive women. This $1,200 scholarship honors the memory of Amelia Earhart, aviatrix and a member of Zonta, and is given annually for graduate study in aeronautical engineering. As its recipient, Mrs. Fila is now working toward a Ph.D. degree in aeronautical engineering at the University of Texas.

▶ **C. Towner French** (AM), Director of Military Sales, Fairchild Camera and Instrument Corporation, was recently elected to the Council of the Institute of Navigation for 1953–1954.

▶ **Geraid Graziani** (TM), who was graduated last June from California Institute of Technology with a Master

(*Continued on page 76*)

Necrology

M. N. Pack

Mendel Nathan Pack, AFIAS, former aeronautical engineer, was killed on June 13 when the Beech Bonanza that he was piloting crashed about 10 miles southeast of Millville, N.J., during a local thunderstorm.

Mr. Pack, who was born in New York City on August 22, 1907, received his B.S. degree in Mechanical Engineering from New York University in 1928. He took graduate work at Massachusetts Institute of Technology and was graduated from there in 1931 with an M.S. degree in Aeronautical Engineering.

Between 1928 and 1938—except for the time spent at M.I.T.—Mr. Pack was an Assistant Engineer with the U.S. Army Air Corps, Wright Field, Ohio. He joined the St. Louis Airplane Division of Curtiss-Wright Corporation in 1938 and served there as Head of the Structures Department. At the time of his death, he was Vice-President of Rodney Feed Company, Millsboro, Del.

Mr. Pack was active in the Civil Air Patrol, holding the rank of Major.

Carl J. Stubau

Carl John Stubau, MIAS, a Mechanical Engineer working independently, died on June 14 at the age of 33.

Mr. Stubau, who was born in Cleveland, Ohio, attended high school in Cleveland Heights. In 1939, he matriculated at the Case School of Applied Science and was graduated in 1942 with a B.S. degree in Mechanical Engineering. Immediately thereafter, he began working at Case on a Master's degree in fluids and aerodynamics.

From May to November of 1942, he worked as a Research Engineer for Cleveland Automatic Machine Company. At the latter date, he became associated with the Pesco Products Division of Borg-Warner Corporation, first as a Test Engineer and later as a Project Engineer. In April of 1945, he left Pesco Products to become a Development Engineer for The Weatherhead Company, where he remained for approximately 2 years. At the end of that time, he rejoined Borg-Warner's Pesco Products Division as Project Engineer. About 1949, he returned to the employ of The Weatherhead Company for a short time.

A private project of Mr. Stubau's was an experimental tandem-wing single-place aircraft. He began the first design work on this about 1947 and some time later started its actual construction. In a letter written by Mr. Stubau last January, he stated that at that time his plane was 90 per cent completed.

Dr. Richard von Mises

Dr. Richard Edler von Mises, FIAS, died in Boston on July 14. He had retired the previous month as Gordon McKay Professor of Aerodynamics and Applied Mathematics, Emeritus, at Harvard University.

Born in Lemberg, Austria, on April 19, 1883, Dr. von Mises studied at the University and the Technical College of Vienna. He was graduated in 1906 as a Mechanical Engineer and in 1908 as a Doctor of Technical Sciences. From 1905 to 1908, he worked as Engineer in several engine factories and at the same time was Assistant and later Design Engineer at the Technical College of Brünn, Austria.

Between 1908 and 1911, he taught at Brünn and at the University of Strassburg in Alsace. For the ensuing 2 years, he headed the Technical Service of "Prinz Heinrick Air Races" and published the "first theoretical formulae suitable to value aircraft performances in flying races." He learned to fly in 1913 and was awarded Federation Aeronautique Internationale (F.A.I.) Certificate No. 500.

During World War I, Dr. von Mises was a Leutnant and later an Ober Leutnant in the Austro-Hungarian Air Force. In 1915 and 1916, a 600-hp. bomber, "Mises," was built under his direction and according to his designs. In the last 2 years of that war, he was Chief of the Department for Aeroplane Supply for the Austro-Hungarian Air Force.

In the 2 years following World War I, he taught at the University of Frankfort and University of Dresden. In 1920, he was appointed Professor and Director of the Institute of Applied Mathematics at the University of Berlin, where he remained until Hitler's rise to power in 1933. At that time, he left Germany and went to Turkey where he served for the next 6 years as Professor of Mathematics at the University of Istanbul. In 1939, he emigrated to the United States and for the ensuing 5 years held a chair of mathematics at Harvard University. In 1944, he was named Gordon McKay Professor of Aerodynamics and Applied Mathematics at Harvard.

Dr. von Mises was the author of many published works covering many diverse subjects, such as aerodynamics, mechanics, statistics, philosophy, and literature. Some of these appeared in German; others, in English. In 1918, his book on the Theory of Flight, *Fluglehre*, was printed by a publishing firm in Berlin; the fifth edition of this work came out in 1936. (His "Theory of Flight" lectures had been printed privately in three editions prior to 1918.) Volumes I, II, and III of *Advances in Applied Mechanics*, which he coedited with Dr. Theodore von Kármán, HFIAS, were published in 1948, 1951, and 1953, respectively. In collaboration with Gustav Kuerti, MIAS, and William Prager, AFIAS, he put out a book entitled *Theory of Flight* in 1945. Some of his other writings have included these titles: *Probability, Statistics and Truth; Notes on Mathematical Theory of Probability and Statistics;* and *Positivism: A Study in Human Understanding.*

In 1935, Dr. von Mises was awarded an honorary degree of doctor by the University of Brussels. Two years ago, in 1951, he received an honorary doctoral degree from the Technical University of Vienna.

Dr. von Mises is survived by his widow, Hilda Geiringer von Mises, Professor of Mathematics at Wheaton College.

Annual Summer Meeting Dinner

Hotel Statler, Los Angeles, July 15, 1953

Guest Editorial

by

James H. Doolittle

Vice-President, Shell Oil Company

IAS Past-President

General Curtis E. LeMay (*left*), General Doolittle (*center*), and IAS President Charles J. McCarthy inspecting Wright reproduction at Los Angeles.

Annual Summer Meeting Dinner Remarks

You all know the story of Kitty Hawk. There is no need to retell it here. And you all appreciate the importance of aviation in modern society. If it were not so important, many of you would be differently employed. The fact that we are going to dedicate a reproduction of the original Wright Flyer here this evening confirms our interest in aviation's past and our confidence in its future.

However, this occasion and the history associated with it suggest three aspects of the progress of science which have a direct bearing on future developments in aviation. I should like to consider them briefly.

The first is the scientist's attitude toward his achievement.

The second is the character of the atmosphere in which a new idea must survive and grow.

The third is the inevitability of growth for a new idea, if the idea is good.

Materialists and idealists probably will never agree on the motive of the inventor. Is hope of profit stronger than dedication to service? Is love of fame greater than desire for knowledge? Actually, it probably varies with the individual. Until we can look into a man's soul, we will never know. And, for our present purpose, it really doesn't matter. What does matter is the practical significance the Wrights attached to their work. Here it is in a letter Orville Wright wrote in 1928 to Senator Hiram Bingham. He said, in part: "Wilbur and I did not take nearly so much pride in the fact that we were the first to fly as we did in the fact that we were the first to have the scientific data from which a flying machine could be built."*

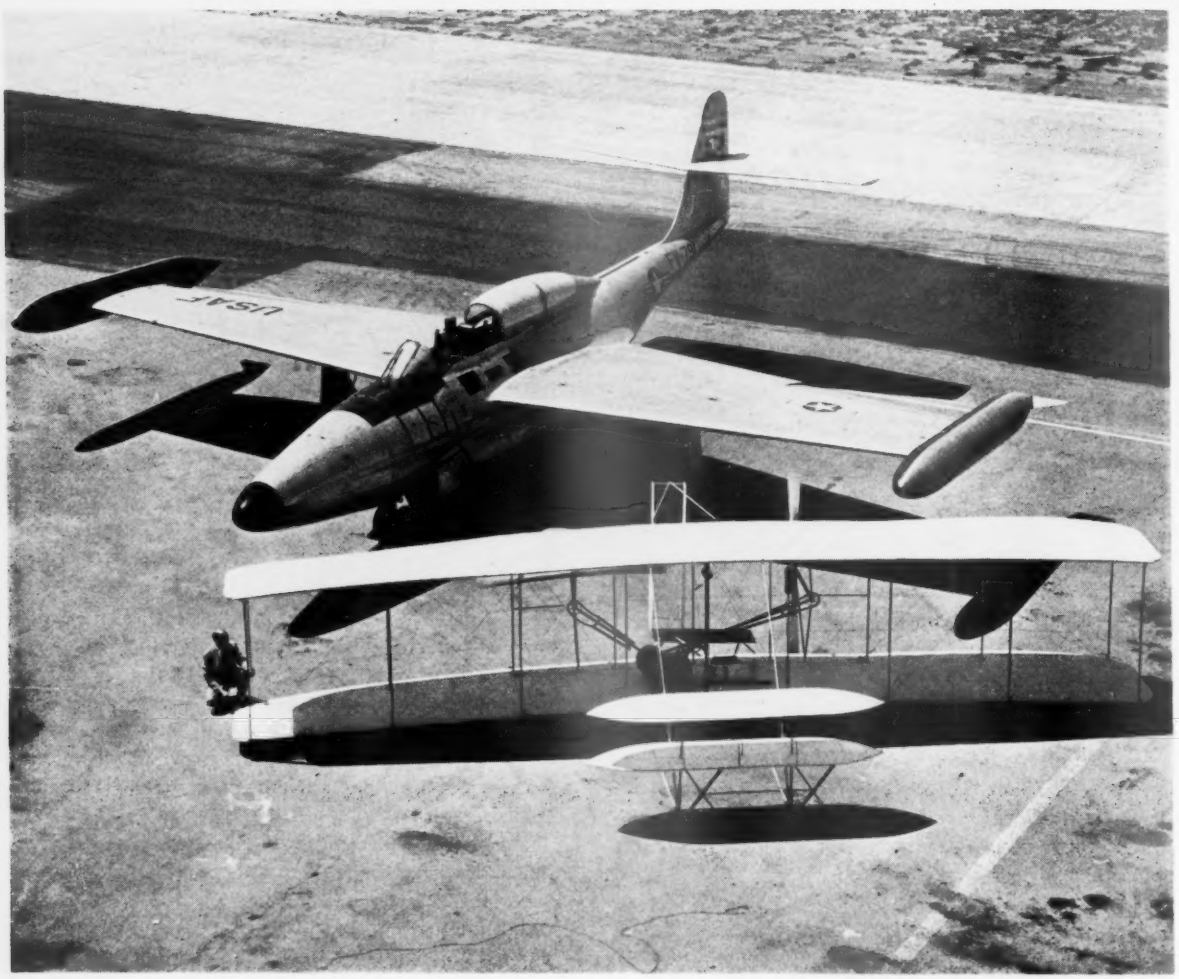
Orville did not deny their pleasure in being first to accomplish a feat that able men had declared impossible. But the Wrights saw that their great contribution was in developing a body of information. Orville made his statement all the stronger by putting it in the passive voice—"data from which a flying machine *could be built*," not by the Wrights alone but by others as well. There you have the significance and the value of research; it provides a sound point of departure for further growth.

The second point, concerning the atmosphere in which a new idea must make its way, is essentially a problem. The rapid technological advances of the past 50 years—by pushing back the borders of the unknown and making the public more aware of the potentials of science—are whittling the problem away. But it is far from gone. The problem is largely a matter of overcoming intellectual inertia. For the Wrights, this meant more trouble after Kitty Hawk than before. There was needling ridicule; there was flat skepticism; and beyond these, there was an encompassing mass of indifference. They were charlatans. No, they were just harmless crackpots, good for a laugh. What could they do that others had not already done with gas bags? Why were they wasting their time trying to fly around a cow pasture when they should be attending to their bicycle business? What would it prove if they did fly? The whole business was against nature. Ignore it!

It is easy, from the vantage point of 1953, to laugh at people who laughed when the Wrights set out to fly. It is not quite so easy to laugh at people who tell us today that certain technical projects or operational procedures are no good and who base their arguments on the ground that the ideas have been tried before and didn't work. Additional knowledge can make easy of accomplishment that which was previously impossible. The way through this somewhat murky atmosphere is not easy, even if you are endowed with true brilliance. At the least, it takes intelligence, foresight, and a good measure of courage to start. It takes persistence and

(*Concluded on page 27*)

* *A Machine to Fly*, Harpers, page 17, June, 1953.



50 YEARS OF AVIATION PROGRESS: The USAF Scorpion F-89 all-weather interceptor, built by Northrop Aircraft, Inc., is a marked contrast to the Wright Brothers' Kitty Hawk airplane, as shown by this comparative photo taken of the F-89 alongside a full-scale reproduction of the historic craft. The progress of aviation from 1903 to 1953 is demonstrated by the fact that the Wright Brothers flew 120 ft. in 12 sec. in 1903, while the F-89 travels over 2 miles in the same time today.

The Wright Reproduction

by Beverly A. Dodge

On December 17, 1903, Orville Wright carved a permanent niche for himself and his brother, Wilbur, by flying a Wright-designed power-driven heavier-than-air machine a distance of 120 ft. in 12 sec. This was man's first free, controlled, and sustained flight in such an aircraft. Later that same day, Wilbur Wright lifted the machine from the wind-swept sands of Kitty Hawk, N.C., to remain aloft for 59 sec. and to cover a distance of 852 ft. Thus began a new era of transportation.

This historic aircraft had an empty weight of 605 lbs. and a gross weight of 750 lbs. Its wing span was 40 ft., 4 in.; overall length, 21 ft., 1 in.; height over the wings, 8 ft., 1 in.; and height over the sweep of the propellers, 9 ft., 4 in. The wings had a chord of 6 ft., 6 in., a camber of 1 in. in 20 in., an incidence of 3°21′, and a 10-in. wing droop. The total wing area, including both the upper and the lower wings, was 510 sq.ft. The loading was 1.47 lbs. per sq.ft. of wing area and 6.25 lbs. per engine hp.

The power plant for this craft was a four-cylinder four-cycle horizontal liquid-cooled gasoline-type engine with a 4-in. bore and 4-in. stroke. Bare of all accessories, it weighed 152 lbs.; with the magneto and ac-

cessories, the engine tipped the scales at 170 lbs. For the first 15 sec. after being started, it developed 16 hp. at 1,200 r.p.m.; however, within a minute or two, the output dropped to about 12 hp. Two contrarotating propellers, each 8 ft., 6 in. in diameter, were located about 10 ft. apart on tubular shafts and were driven by chains running over sprockets.

Fifty years later, a full-scale reproduction of this Kitty Hawk airplane was dedicated by Lt. Gen. James H. Doolittle, USAF (Ret.), Chairman of the National Committee to Observe the Fiftieth Anniversary of Powered Flight. (See p. 23.) The only full-scale model of the original in the Western Hemisphere, it was installed last July as a permanent exhibit in the W. F. Durand Aeronautical Museum of the Institute of the Aeronautical Sciences in Los Angeles. (The original Wright Brothers' plane can be seen at the Smithsonian Institution's National Air Museum in Washington, D.C.)

This West Coast reproduction is the realization of an idea long cherished by E. W. Robischon, IAS Western Region Manager. It is the result of the cooperative effort of more than 20 companies broached by Mr. Robischon. Each of these companies enthusiastically supported the idea and readily agreed to reconstruct and contribute the components required for the completed project.

One of the contributing companies, Diamond Chain Company, Inc., brought out some long-retired dies and with them provided the type of chains used on the original Wright plane. Longines-Wittnauer Watch Company, Inc., obtained a French copy of the original Wright anemometer, which is also believed to have been of French manufacture. A third contributor, Schrillo Aeronautical Tool Engineering Company, reproduced in complete external detail an old motorcycle hub used by the Wright Brothers as a roller for the launching track.

The reproduction's engine is an accurate wood and metal mock-up of the original power plant and was built by Marquardt Aircraft Company employees on their own time. Charles F. Taylor, builder of the original Wright engine, was at the Marquardt plant for the ceremony in which the mock-up was donated to Marquardt Aircraft Company for presentation to the reproduction project.

And so it went, each company doing its utmost to make the reproduction true to the original in exacting detail.

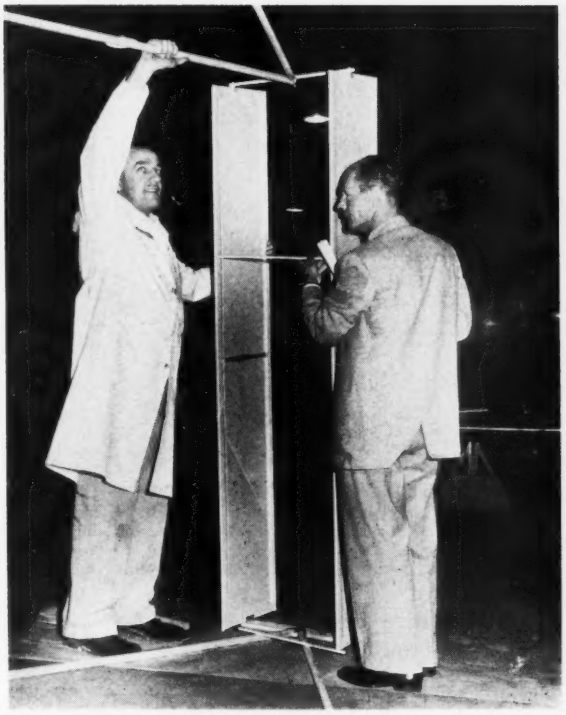
A complete listing of the companies and the components contributed by each to this reproduction are as follows:

American Helicopter Company, Inc.—Propeller support structure, propeller chain casings and supports.

Apex Wire and Alloys Corporation—All brace wires.

Cal-Aero Technical Institute—Wing struts, skid framing, stays.

Diamond Chain Company, Inc.—Propeller chains, control system chains, engine chains.



PACIFIC AIRMOTIVE CORPORATION: Rudder for the reproduction of the Wright Brothers' plane built by Pacific Airmotive Corporation. P.A.C.-veterans Paul W. Jones and Charles Osborne completed the handmade rudder almost entirely on their own time.

Flightex Fabrics, Inc.—All fabric.

The B. F. Goodrich Company—All rubber hose and tube.

Lockheed Aircraft Corporation—Project coordination; support and hoist system for IAS building.

Longines-Wittnauer Watch Company, Inc.—Anemometer, stop watch.

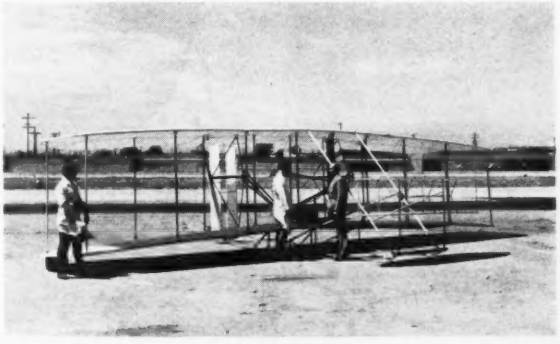
Los Angeles Trade-Technical Junior College—Complete elevator assembly and support structure.

Manco Plating Company—All metal plating.

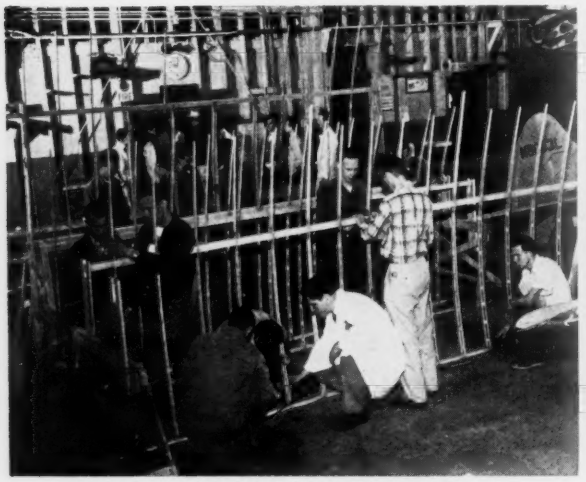
Marquardt Aircraft Company—Complete engine mock-up.

Meletron Corporation—Flight instrument assembly.

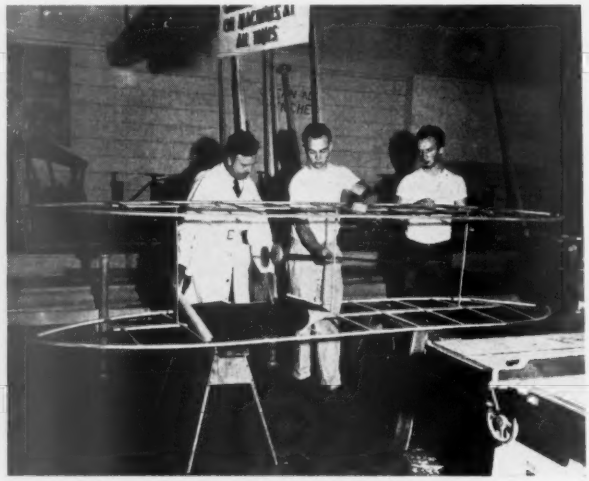
Northrop Aeronautical Institute—Complete wing panels, all assembly and rigging work.



The Wright Reproduction.



NORTHROP AERONAUTICAL INSTITUTE: Students of the Northrop Aeronautical Institute assemble structure for wing cellules of Wright reproduction. Wings were constructed using hard woods similar to those used by the Wrights for Kitty Hawk airplane.



LOS ANGELES TRADE-TECHNICAL JUNIOR COLLEGE: Elevator assembly framework being erected by the Junior College students in their woodshop. Fragile construction of original machine is apparent here.

Pacific Airmotive Corporation—Complete rudder assembly and support structure.

Schrillo Aeronautical Tool Engineering Company—Strut clips, propeller shafts, chain adjusters, elevator roller.

F. Somers Peterson Company—Engine revolution counter.

Southern Counties Gas Company of California—Fuel system cocks.

E. J. Stanton and Son, Inc.—All hard woods.

Stolper Steel Products Corporation—Fuel tank and brackets.

Timm Industries, Inc.—Control levers, pulleys, clips, supports.

U.S. Propellers, Inc.—Two propellers.

Western Gear Works—All engine and propeller gears.

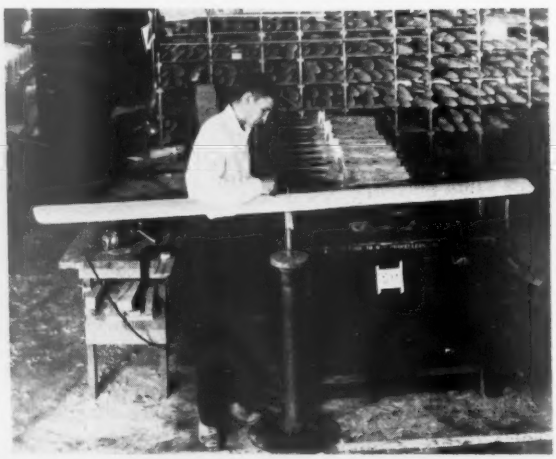
Young Radiator Company—Engine radiator and clips.

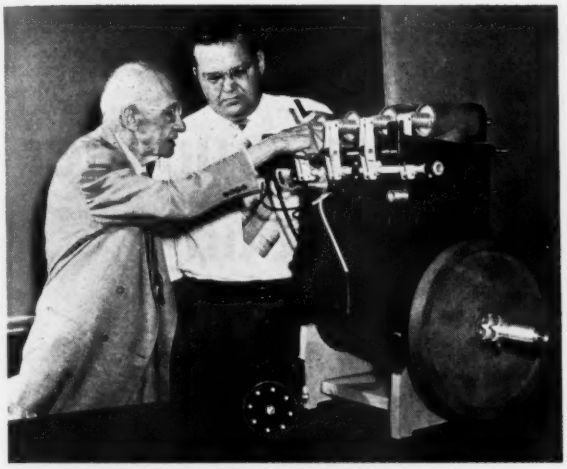
After several of the companies had committed themselves to supply specific parts, Mr. Robischon contacted John K. Northrop and James L. McKinley, of Northrop Aeronautical Institute. It was agreed that N.A.I. would not only fabricate the wing cellules but would also handle the final assembly. As a result, throughout last winter and spring, one section of the N.A.I. hangar at Northrop Field was given over completely to its construction, which began in November of 1952. The work was accomplished by the Northrop students under the direction of Ralph Bent and as a part of the school curriculum.

The blueprints used to construct this West Coast reproduction were obtained from The Science

AMERICAN HELICOPTER COMPANY: Propeller chain casing supports being assembled by American Helicopter Company technicians. Propellers on original machine were chain-driven through tubular shafts placed 10 ft. apart.

U.S. PROPELLERS, INC.: One of two propellers for Wright reproduction being finished in shops of U.S. Propellers, Inc. The Wrights used two 8-ft., 6-in. diameter chain-driven propellers running in opposite directions.





MARQUARDT AIRCRAFT COMPANY: Charles Taylor, Dayton mechanic, who built engine for original Wright Airplane, points out ignition camshaft of reproduction engine to Roy Marquardt, of Marquardt Aircraft Company. The reproduction duplicates original engine down to such details as valve-cage assemblies and magnet.

SOUTHERN COUNTIES GAS COMPANY: Southern Counties Gas Company machinist threads gasoline-line cock for Wright reproduction. Original Wright airplane carried less than ½ gal. of fuel.

Museum in London, England, where the only other existing full-scale model was built and is now on display. These Kensington drawings were later supplemented by data from our National Air Museum.

The coordination of the project was handled by F. A. Cleveland, of Lockheed Aircraft Corporation. Mr. Taylor, the Wright engine builder, contributed valuable technical assistance.

The Wright reproduction is a tribute to the work begun by the Wright Brothers over 50 years ago and to the aeronautical advancements made during the half century that ends on December 17, 1953. It represents a science that, in the words of Brig. Gen. Frank P. Lahm, USAF (Ret.), "may well lead *beyond* the conquest of the air which surrounds this small planet on which we live."

Guest Editorial by James H. Doolittle

(*Concluded from page 23*)

faith in your data and in your application of them to keep going. The Wrights had these qualities.

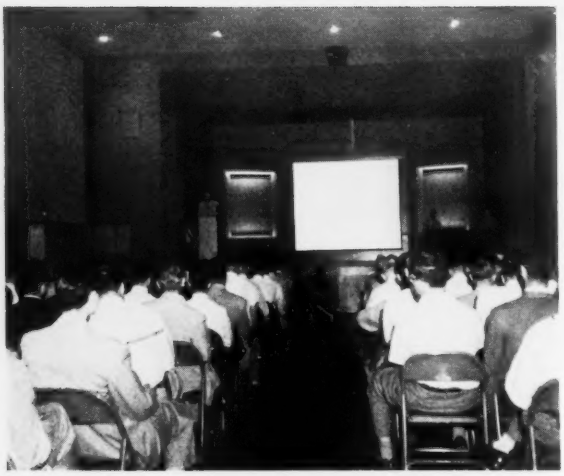
The results of their work give us a clear illustration of the third point—the inevitability of the spread of a good idea. We must not overlook the word *good*. In the Middle Ages, the alchemists considered it a good idea to try transmuting base metals into gold. It couldn't be done then. In 1903, a few weeks before Kitty Hawk, a famous scientist* attempted to prove, mathematically, that it would be impossible to build a flying machine that would carry a man. To his own satisfaction and to that of many others he succeeded. Who remembers his name?

Even for the soundest ideas, intellectual inertia is an enormous obstacle at first. But as proof follows proof, the inertia is eventually converted to interest. A kind of Gresham's-law-in-reverse begins to operate, with good ideas driving out bad. Momentum begins to build up. Active suppression may delay progress, but once a good idea gets going nothing can permanently stop it.

When a good idea starts to grow the initiator may have to fight to retain control of it. Human nature being what it is, there will be a tendency for him to be shoved to one side by more aggressive contemporaries. But this need not be. There is no good reason why a man should not receive reasonable rewards for his originality and his effort. However, within the limits required by protection and compensation for originality, the general welfare demands that good ideas be permitted full and easy growth.

Any organization devoted to this principle is worth while because it fulfills a basic requirement of civilization. It serves mankind. It does its part to make this world a better place.

* Professor Simon Newcomb, prominent scientist and mathematician. Wright, Orville, *How We Invented the Airplane*, edited by Fred C. Kelly, Harpers, page 26, June, 1953.



Annual Summer Meeting

Report of Technical Sessions

(ED. NOTE—The following reports of the technical sessions have been filed by the individual session chairmen. Most of the papers presented are being published in early issues of the REVIEW and JOURNAL. Preprints of papers available are listed on page 48 of the August REVIEW.)

Aerodynamics Session

Harry J. Heimer, Chairman

Technical Staff Member, Hughes Aircraft Company

The Guest Chairman of the Aerodynamics Session of the Annual Summer Meeting of the Institute of the Aeronautical Sciences was Capt. Walter S. Diehl, USN (Ret.). The first paper was by H. R. Lawrence and A. H. Flax, of the Cornell Aeronautical Laboratory, Inc., on the subject "Wing-Body Interference at Subsonic and Supersonic Speeds: Survey and New Developments." The paper was presented by Mr. Lawrence, who was able only to summarize the thorough and complete written version of the paper. Most of the various theories and techniques of calculating wing-body interference were compared and discussed. Methods for high and low aspect ratio and subsonic and supersonic Mach Numbers were considered. Experimental data were compared with the various theories to evaluate their usefulness. It was also shown how a unified point of view in constructing approximate theories and design methods and in interpreting and utilizing experimental data for all speed ranges can be achieved by the application of general integral relations using linearized theory.

The second paper was by Edward S. Rutowski, of Douglas Aircraft Company, Inc., on the "Energy Approach to the General Aircraft Performance Problem." In this paper methods of performance calculations using an energy approach were discussed. Total aircraft energy becomes the major independent variable. Techniques were discussed for finding the path of minimum time and minimum fuel to change from one combination of speed and altitude to another. The method is also useful in range calculations and leads to a range equation based on the heat content of the fuel and the overall power-plant efficiency. In addition to being useful for performance calculations on a given airplane, the method would appear to be especially useful in comparing different types of power plants.

The third paper was on the "Applications of Hypersonic Thin-Body Theory" by Milton D. Van Dyke, of the NACA Ames Aeronautical Laboratory. Dr. Van Dyke showed that the hypersonic similarity rule of Tsien and Hayes can be used throughout the usual range of the linearized theory, as well as in the hypersonic range. Thus a single theory, together with a single similarity rule, covers the entire supersonic range from just above the transonic range to infinite Mach Numbers.

The applicability of the method was shown using the calculation from Kopal's report on the flow around cones.

A considerable improvement in the method was obtained by interpreting its results in conformity with the Newtonian impact theory. To illustrate the generality and usefulness, the method was applied to the cases of a symmetrical circular cone and an ogival body. Some discussion was given concerning the application of the method to two- and three-dimensional bodies at angle of attack.

The last paper was by Leonard Sternfield, of the NACA Langley Aeronautical Laboratory on "A Vector Method Approach to the Analysis of the Dynamic Lateral Stability of Aircraft." This vector method enables one to determine directly the damping of the dutch-roll oscillation, as well as the amplitude and phase relation between the three lateral degrees of freedom. The application of the method to several other stability problems was also discussed. Based on the method, a "vector machine" has been built for analyzing the two

degrees of freedom of lateral motion—namely, rolling and yawing. A movie was presented which showed the operation of the machine. Through its use it is possible to calculate rapidly the frequency response of a two degree of freedom system.

Propulsion Session

Brooks T. Morris, Chairman

Administrative Engineer, Marquardt Aircraft Company

Because this Session was unclassified, care was taken in the discussion to avoid disclosure of security information; this accounts for the lack of published discussion. The attendance at this Session was 170. The following papers were presented.

"Spreading of Supersonic Jets in Supersonic Streams," by John G. Wilder, Jr., Section Head, Experimental Aerodynamics Section, and Kenneth Hindersinn, Assistant Aerodynamicist, Cornell Aeronautical Laboratory, Inc. (This paper is published in full on page 54 of this issue.)

"Afterburners—Are They Worth While?" by Floyd C. Newton, El Segundo Division, Douglas Aircraft Company, Inc. (This paper is published in full on page 42 of this issue.)

"Optimum Exit-Nozzle Performance for Jet Engines," by Richard G. Laucher, Afterburner Section Supervisor, and John S. Winter, Afterburner Project Engineer, Marquardt Aircraft Company. (See page 41 of the September issue of the REVIEW for this paper.)

"Techniques for Determining Thrust in Flight for Airplanes Equipped with Afterburners," by L. Stewart Rolls and C. Dewey Havill, Ames Aeronautical Laboratory, NACA. This paper discussed an experimental technique that has been developed to determine the net thrust for an afterburner-equipped airplane in flight. Measurements from a swinging pitot-static pressure and total temperature probe were used to determine the gross thrust, total airflow rate, and net thrust. The power-operated swinging probe was used to overcome the shortcomings of using a fixed rake that would require the use of special high-temperature material to withstand the high jet-exhaust temperatures associated with afterburner operation. Use of the swinging probe technique to determine the efficiency of an ejector type tailpipe cooling system was discussed.

Guided-Missile Session

Evert C. Hokanson, Chairman

Sales Administrator, G. M. Giannini & Company, Inc.

A most outstanding presentation of a complete guided-missile weapon system was given before an enthusiastic audience of 400 IAS members at Los Angeles on July 16, 1953. All had been cleared for "Confidential" in order to have the privilege of hearing Guest Chairman Brig. Gen. H. N. Toftoy, W. H. C. Higgins, and E. P. Wheaton tell about how the guided missile was planned, developed, tested, and operated.

General Toftoy, Director of Ordnance Missile Laboratories, Redstone Arsenal, Huntsville, Ala., briefly traced the history of guided missiles from World War II up to the present time. He then told how the project was organized on a weapons system development basis. He emphasized the success of this method and commended the participating contractors for their superb cooperation and understanding in mutually working out each problem as it arose. The 3,000-mile separation of the principal contractors—Bell Telephone Laboratories and Douglas Aircraft Company—did not cause difficulty, primarily because of the products of each—namely, the telephone and transport aircraft. One feature of the program which was believed to contribute greatly toward its success was the subcontracting of components to specialist companies. This resulted in the procurement of the best products possible in the shortest time.

W. H. C. Higgins, Director of Military Systems Development for Bell Telephone Laboratories, discussed the various phases of the guided-missile system from the preliminary study and planning to the details of design and manufacture, which resulted in a finished weapon system. His excellent presentation of the essential features in a program of this magnitude stressed the progressive steps of study, development, evaluation, and training.

E. P. Wheaton, Chief Project Engineer for Guided Missiles, Douglas Aircraft Company, Inc., discussed the problems encountered in the development, design, and testing. He gave a most interesting description of the methods used in solving those problems. Mr. Wheaton's talk was followed by two impressive films showing the guided-missile system, how it operates, and actual flights of the missile from the launching to the contact with drone target aircraft. The use of these films was made possible through the cooperation of the Los Angeles Ordnance District and Douglas. On display at the meeting was a complete guided missile.

Everyone fortunate enough to attend this meeting was enthusiastic about the material and the manner in which it was presented. Comments indicated that seldom, if ever before, had so complete and interesting a story been given on any project. It gave a remarkable overall picture of the progress made on guided missiles, the newest phase in the aeronautical field.

Structures Session

Arthur M. Ogness, Chairman

Supervisor, Preliminary Design Department, Northrop Aircraft, Inc.

"Fatigue Life of Thick-Skinned Tension Joints" by E. W. Thrall, El Segundo Division, Douglas Aircraft Company, Inc. This paper presented fatigue failures

encountered during an integral wing tank life cycling test of an experimental airplane wing. A series of tests was performed in order to determine a splice arrangement that would have a fatigue life equal to the basic unspliced portion of the structure. The results of the tests were presented including the splice arrangement incorporated as a repair on the experimental airplane.

"Optimum Design Consideration for Aircraft Wing Structures," by A. L. Kolom, North American Aviation, Inc. (This paper is published in full on page 31 of this issue.)

"Warping of Thin-Shell Wing Structure," by Joseph A. Wise, University of Minnesota. This paper illustrated the form of the characteristic equation which defines the distribution of strains and deformations in a thin-shell corner-stiffened box. Standard thin sheet-metal assumptions are made in addition to the further assumption that the box contains infinitely closely spaced rigid bulkheads.

Helicopter Design Session

Winfield H. Arata, Jr., Chairman

Preliminary Design Engineer, Lockheed Aircraft Corporation

The Helicopter Design Session was held on the afternoon of July 17, 1953, as a joint meeting of the Institute of the Aeronautical Sciences and the American Helicopter Society. The opening remarks by the Chairman indicated that there was a twofold purpose behind the meeting: first, to give recognition to the growing helicopter industry on the West Coast and, second, to learn about the design features of some of the latest models being built by their manufacturers.

The meeting was then turned over to the Guest Chairman, R. A. Wagner, Chief Engineer, Aircraft Division, McCulloch Motors Corporation, who then introduced each speaker.

The first speaker was J. R. Jones, Project Engineer, McCulloch Motors Corporation, who spoke on "Design Features of the McCulloch MC-4 Helicopter."

The second speaker was Howard E. Roberts, Vice-President, General Staff, American Helicopter Corporation, who spoke on "Design Features of the XH-26 'Jet-Jeep' Helicopter."

The last paper was given by Harvey Holm, Project Engineer, Hiller Helicopters, and was entitled "Design of the Hiller HJ-1, YH-32 Helicopter." (This paper is published in full on page 48 of this issue.)

The questions asked during the discussion period were similar for all three papers. Some of the questions asked were: What is the rate of descent when in autorotation? What is the average specific fuel consumption of the engine? What is the estimated production cost?

After the presentation of the design papers, a film loaned by Sikorsky Aircraft was shown. One portion of this motion picture showed the use of helicopters in Korea. The other part of the film showed the flight of two Sikorskys (H-19) across the North Atlantic Ocean.

In conjunction with the Design Session, there was a static display of the McCulloch MC-4C and American Helicopter XH-26 helicopters in the IAS parking lot. Over 400 people visited the display and attended the Design Session.

Special IAS Publications

	Member Rate	Nonmember Rate
Aeronautical Engineering Index – 1952	$ 3.00	$ 5.00*
1951	2.50	4.00*
1950, 1949, 1948, 1947 (each)	2.00	3.00*
Second International Aeronautical Conference Proceedings	15.00	17.50*
First Convertible Aircraft Congress Proceedings	3.00	5.00*
Second Convertible Aircraft Congress Proceedings	3.00	5.00*
Fifteenth Wright Brothers Lecture—The Experimental Approach to Aircraft Structural Research, P. B. Walker (Reprinted from the March, 1952, and April, 1952, JOURNAL OF THE AERONAUTICAL SCIENCES)	1.00	1.50
Sixteenth Wright Brothers Lecture—Technical Trends in Air Transport, William Littlewood (Reprinted from the April, 1953, JOURNAL OF THE AERONAUTICAL SCIENCES)	1.00	1.50
The Earth's Atmosphere, H. E. Roberts, including 20- by 16-in. colored chart (Reprinted from the October, 1949, AERONAUTICAL ENGINEERING REVIEW)	0.65	1.00
Books on Selected Technical Subjects in the IAS Library (up to 1950), unbound	2.00	2.00*

*Add $1.00 for orders outside the U.S.A.

These may be obtained by writing to

Publications Department, Institute of the Aeronautical Sciences, Inc., 2 E. 64th St., New York 21, N.Y.

Optimum Design Considerations for Aircraft Wing Structures

AARON L. KOLOM*
North American Aviation, Inc.

ABSTRACT

The three basic types of wing structural design—multirib, multistringer, and multispar—are discussed comparatively from the optimum design point of view. Relative weight efficiencies of multirib and multistringer compression surface designs are developed, with calculations and curves of optimum stringer and rib spacing for three types of multistringer structure: light formed "zee," extruded bulb angle, and extruded hat-section stringers.

The advantages and limitations of multispar design are discussed and optimum spar spacing and skin-thickness calculations and design curves presented for a wide range of axial load per inch values.

Summary design selection curves for minimum weight structure are presented for all types of structure considered and covering the entire range of load per inch values expected in aircraft wing design.

SYMBOLS

A = area, sq.in.
A_c = spar cap area, sq.in.
A_R = effective area of distributed rib volume, $A_R = V_R/S$, sq.in.
A_s = stringer area, sq.in.
A_{sp} = effective area of intermediate spar web, multispar design, sq.in.
b = panel width, in.
C = structural chord, in.
E = Young's modulus, lbs. per sq.in.
f = applied stress, lbs. per sq.in.
F_{cc} = spar cap compression allowable, lbs. per sq.in.
F_{cr} = critical panel compression allowable, lbs. per sq.in.
F_{cs} = stringer column allowable, lbs. per sq.in.
F_{cy} = compression yield allowable, lbs. per sq.in.
F_{cmax} = maximum stringer compression allowable (crippling), lbs. per sq.in.
F_{sp} = compression allowable of intermediate spar, multispar design, lbs. per sq.in.
F_{tu} = tension stress allowable, lbs. per sq.in.
F_m = maximum allowable panel compression stress, lbs. per sq.in.
h_s = height of spar, in.
I = section bending moment of inertia, in.^{4}
K = panel edge support coefficient
l = bending moment couple arm, in.
M = bending moment, in.lbs.
n = number of stringers
P = couple load, lbs.
P_{cr} = rib crushing load per stringer, lbs.
Q = axial load per in., lbs. per in.
S = rib spacing
t = skin thickness, in.
$t_{speff.}$ = effective thickness of intermediate spars, multispar structure, in.
u = Poisson's ratio
V_R = volume of rib, in.^{3}
w = effective width of skin in compression, in.
y = distance from neutral axis
ρ = radius of gyration, in.
η = coefficient that allows for the reduction of E for compression stresses above the proportional limit.

Presented at the Structures Session, Annual Summer Meeting, IAS, Los Angeles, July 15–17, 1953.

* Supervisor, Wing structures.

INTRODUCTION

THE DESIRED GOAL in aircraft structural design is the optimum configuration of structural material to support the given design loads. One of the more important criteria for optimum design is the achievement of a practical minimum structural weight that is consistent with design and servicing requirements at the greatest economy of manufacturing cost. Minimum weight is also becoming increasingly important with present-day, high-speed, long-range aircraft, where each excess pound of structure can have a material reflection in performance, pay load, or operational expense.

For the lower surface of the wing which is designed primarily by tension loads, minimum weight is achieved in a fairly simple manner. Aluminum alloys with the highest tension allowables are used, with as much material as possible concentrated at the farthest distances from the neutral axis of the wing section. The upper or compression surface, however, because of the wide range in column or crippling allowables obtainable with different stringer types, former spacing, etc., and the complications of special design requirements, presents the most difficult problems for attaining economical structural weight.

General Types of Wing Structure

There are three general types of compression surfaces, as shown in Fig. 1: multirib design, type A, with all of the compression load being carried by the spar caps alone, utilizing closely spaced ribs to support the skin and form the airfoil contour; multistringer design, type B, with unlimited variations of stringer types and effective skin combinations acting with the spar caps to support the compression loads; and multispar design, type C, with all of the compression load being carried by the skin, which is supported by closely spaced spars.

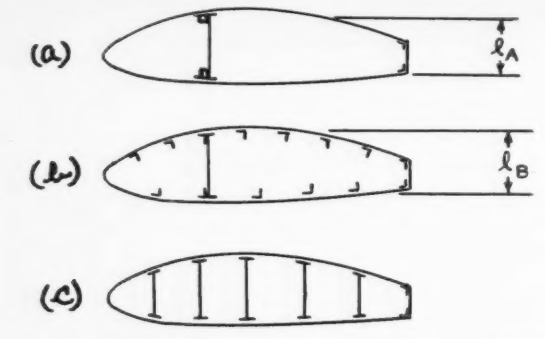


FIG. 1. General types of wing structural design. (a) Multirib design, type A. (b) Multistringer design, type B. (c) Multispar design, type C.

OPTIMUM DESIGN CONSIDERATIONS

At the initiation of a wing design, the optimum type of structure can be ascertained fairly readily from the couple load requirement at the critical wing stations. With the transition of aircraft performance and design configurations from low-speed airplanes with lightly loaded thick airfoil wings to present-day high-speed aircraft, the optimum type of structural design has also undergone changes from multirib design or type A through multispar design or type C, the latter being the only practical design for heavily loaded extremely thin wings.

The primary function of the intermediate spars for multispar structure is to support the skin plates under the crushing forces due to flexural bending; and very light corrugations or adequately stiffened spar webs will provide such support for even very thick plates. Where it can be used, therefore, multispar design lends itself readily to minimum weight structure. With the skin fully effective in compression, and capable of supporting stresses in the neighborhood of F_{c_y}, this type of structure is by far the most efficient. As the trend continues toward thinner and thinner wing sections with large axial loads per inch, multispar design will undoubtedly find increasingly widespread usage in future aircraft wing design.

For the predominant number of aircraft being designed today, however, whose structural geometry and loading makes the multirib or multistringer type more practical, the problems of optimum design and stringer and rib spacing are extremely important. It is with these two types of structure, therefore, that direct weight comparison studies need be made.

When a conventional wing design is undertaken, the airfoil shape and spar locations are generally set by considerations other than structural weight efficiency. A bending moment couple arm can then be estimated for each design type, the arm for type A being smaller than for type B because the spar caps are not generally located at the chord percentage points of maximum depth and also because the requirement of larger spar cap areas further lowers the compression area center of gravity location.

The advantages and disadvantages of each type of design can be summarized as follows:

Multirib Structure

In multirib structure, the spar caps carry the entire compression load, ribs are relatively closely spaced with no stringers, and the skin gage is a minimum as determined by wing torsion or flutter.

Advantages:

(1) Easy fabrication, no stringer cutouts in ribs.

(2) Load concentrations in spar caps are ideal for bolting or wing folding joints.

(3) Minimum weight skins.

(4) Minimum weight penalty for skin cutouts and access doors.

(5) Generally reduced skin shear flows.

Disadvantages:

(1) Smaller bending moment lever arm; therefore higher couple loads and greater area requirements for tension, as well as compression surfaces.

(2) Closer rib spacing required for carrying air loads into spars than for stringer-type design.

(3) Handling difficulties with thin skin.

(4) Undesirable aerodynamic effects caused by compression buckles forming between ribs as a result of spar cap axial deformations under load.

(5) Skin weight of no benefit in carrying wing bending.

(6) Average compression stresses are higher than for design type B; therefore, wing deflections are greater.

Specific design requirements for any particular aircraft may in effect dictate the type of design which is most advantageous. Special considerations in favor of design type A are:

(1) Wing folding joints, where all the load must be concentrated in the spar caps at certain points.

(2) A high degree of maintenance accessibility, with a multitude of skin cutouts and access doors.

Multistringer Structure

In multistringer design, conventional stringers and effective skin panels act in conjunction with the spar caps to carry compression forces. Optimum weight design is obtained by using the highest compression allowable stringer that is consistent with the area requirements and so spaced as to derive maximum benefit from the skin in compression.

Advantages:

(1) Maximum average lever arm for bending material resulting in reduced loads and area requirements for both upper and lower surfaces.

(2) Utilization of all skin for bending, as well as torsion loads.

(3) Excellent skin-buckling and wing-twist characteristics.

(4) Relatively few ribs or formers.

(5) Good service-handling characteristics and general rugged appearance.

(6) Average compression stresses are lower than for design type A; therefore, deflections are smaller.

Disadvantages:

(1) More fabrication difficulties than design type A due to stringer cutouts and riveting.

(2) Unsuited for efficient bolting or wing folding design.

(3) Weight and fabrication penalties for skin cutouts or access doors.

Special considerations in favor of design type B are:

(1) Wing flutter or aileron divergency requirements that specify a minimum skin thickness that is fairly substantial.

(2) Wing fuel tanks with large unsupported bays favoring double skin construction.

Most conventional wings are designed with stringers, the common process of design being the selection of minimum skin gages for shear flow or for practicality of handling, flutter, or aileron divergency requirements. Stringer and former spacings are then selected so as to achieve the best compromise between high stringer column allowables, effective rib area, the utilization of as much effective skin as is economically feasible, fabrication cost, and the limitations of undue panel buckling.

Since the advantages of specialized types of design, as well as loads per inch, chord lengths, and many other factors, vary along the wing span, the optimum type of design may also vary spanwise, with the most efficient overall design being a compromise for the entire wing.

Effective Width of Skin

The actual effective width of compression skin acting in conjunction with the stringers and spar caps is dependent upon the compression allowable of the supporting item since the skin between stringers buckles out more and more with increasing stress. Calculations of the effective skin width resolve into equations such as

$$w = 1.90t\sqrt{E/F_{cs}} \quad \text{(reference 1)}$$

which for nominal skin thicknesses and stringer stresses can be approximated at $w = 30t$. True effective width calculations are generally impractical, and the calculations of stringer allowables from test results where $30t$ of skin is used in the reduction of the test data will minimize any errors.

Multirib and Multistringer Design

For simplicity in calculations and because wings are generally flat, the concept of couple loads and average stresses is employed rather than the conventional bending section analysis of My/I.

The areas required for each design type are shown below, with $60t^2$ of effective skin being assumed to act in conjunction with the total area of the two spar caps.

The bending moment,

$$M = P_A \cdot l_A = P_B \cdot l_B$$

therefore

$$P_A = (l_B/l_A)P_B$$

For design type A,

$$P = f \cdot A = F_{cc}[\Sigma A_c + 60t^2]$$

therefore

$$\Sigma A_c = \frac{P_A}{F_{cc}} - 60t^2 = \frac{M}{l_A \cdot F_{cc}} - 60t^2$$

As the smaller couple arm l_A results in a larger tension area, as well as compression area, for type A design, the additional required tension area is as follows:

$$\Delta A = \frac{M}{l_A \cdot F_{tu}} - \frac{M}{l_B \cdot F_{tu}} = \frac{M}{F_{tu}}\left(\frac{1}{l_A} - \frac{1}{l_B}\right)$$

The total area for comparison purposes, therefore, including ineffective skin and the distributed rib weight, is then

$$A_{\text{tot.}}{}^{A} = A_{\text{tot.}}{}^{A} + \Delta A = \Sigma A_c + Ct + A_R{}^{A} + \Delta A$$
$$= \frac{M}{l_A \cdot F_{cc}} + \frac{M}{F_{tu}}\left(\frac{1}{l_A} - \frac{1}{l_B}\right) - 60t^2 + Ct + A_R{}^{A} \quad (1)$$

Also for type B,

$$P_B = f \cdot A = F_{cc}[\Sigma A_c + 60t^2] + F_{cs}[\Sigma A_s + 30nt^2]$$

Therefore,

$$\Sigma A_c = \frac{P_B}{F_{cc}} - \frac{F_{cs}}{F_{cc}}[\Sigma A_s + 30nt^2] - 60t^2$$

The total area is then

$$A_{\text{tot.}}{}^{B} = \Sigma A_c + \Sigma A_s + Ct + A_R{}^{B}$$

or

$$A_{\text{tot.}}{}^{B} = \frac{M}{l_B \cdot F_{cc}} - n\frac{F_{cs}}{F_{cc}{}^{B}}[A_s + 30t^2] -$$
$$60t^2 + nA_s + Ct + A_R{}^{B} \quad (2)$$

Spar Cap Excess Compression Allowable

One of the considerations of increasing importance in efficient compression surface design is the utilization wherever possible of the high spar cap allowables resulting from the restraint against column failure provided by the spar web and stiffeners. This can be achieved even in multistringer structure, by designing the stringers for column failure at some point below the ultimate but for practical purposes above the limit or applied load. The excess bending is then carried by the spar caps, which are thus worked to a higher stress than the stringers. Too great a differential between the spar cap and stringer allowables should be avoided, however, especially where principal wing design conditions combine high torque with high bending. The effects of skin shear flow upon the skin-stringer compression panel must, in these instances, be carefully

considered, since the resulting skin buckles may induce stringer collapse and consequently premature wing failure well before the spar caps are loaded to their theoretical capacity. This is especially true with stringers that are subject to torsional instability.

Comparative Weight Efficiencies

Although the higher average compression allowables attainable with design type A seem to indicate it would be the most efficient weightwise despite its smaller couple arm and ignoring any minimum skin-thickness requirements, there are two reasons why this is generally not so:

(1) The effective skin used for compression in multistringer design may offset the higher average compression allowable of design type A.

(2) The weight of the supporting formers, which are generally more closely spaced in A than in B, is far from negligible and may provide a weight differential in favor of the multistringer type of design. This former weight, which is so often overlooked, is so important that often the best overall weight design of a stringer panel is obtained by selecting a former spacing such that the stringer column allowable is considerably below the maximum attainable, as is demonstrated later.

The comparative weight efficiencies of the two types of design can be analyzed as follows:

$$\Delta A = A_{\text{tot.}}{}'^{A} - A_{\text{tot.}}{}^{B} \tag{3}$$

Thus, when $\Delta A > 0$, the weight advantage is in favor of skin-stringer structure or design type B. From Eqs. (1) and (2)

$$\Delta A = \frac{M}{l_A \cdot F_{cc}{}^{A}} + \frac{M}{F_{tu}}\left(\frac{1}{l_A} - \frac{1}{l_B}\right) + A_R{}^{A} - \frac{M}{l_B \cdot F_{cc}{}^{B}} - \Sigma A_s - A_R{}^{B} + \left(\frac{F_{cs}}{F_{cc}{}^{B}}\right)(n)[A_s + 30t^2]$$

This can be reduced to

$$\Delta A = [A_R{}^{A} - A_R{}^{B}] + \left(\frac{F_{cs}}{F_{cc}{}^{B}}\right)(n)(A_s + 30t^2) - nA_s + M\frac{1}{l_A}\left(\frac{1}{F_{cc}{}^{A}} + \frac{1}{F_{tu}}\right) - \frac{1}{l_B}\left(\frac{1}{F_{cc}{}^{B}} + \frac{1}{F_{tu}}\right) \tag{3'}$$

For the first group of terms $[A_R{}^{A} - A_R{}^{B}]$, the lack of stringers in design type A will require closer rib spacing to support air loads and retain the airfoil contour than for the stringer type of design. Consequently $[A_R{}^{A} - A_R{}^{B}] > 0$.

The relationship of stringer area to skin thickness in a well-balanced design is generally from $1.0t$ to $2.0t$. Conservatively assuming the larger value or 2 in. equivalent skin length, $A_s = 2.0t$, the second group of terms

$$n[(F_{cs}/F_{cc}{}^{B})(A_s + 30t^2) - A_s]$$

is reduced to

$$nt\left(\frac{F_{cs}}{F_{cc}{}^{B}}\right)\left[30t - 2\left(\frac{F_{cc}{}^{B}}{F_{cs}} - 1\right)\right]$$

The second group of terms has positive values, therefore, when

$$30t > 2[(F_{cc}{}^{B}/F_{cs}) - 1]$$

or when

$$t > 0.067[(F_{cc}{}^{B}/F_{cs}) - 1]$$

Because of the inherent danger of premature stringer collapse and general instability failure when an attempt is made to carry excessive spar cap stresses in conjunction with low stringer allowables, it is generally undesirable to permit $F_{cc}{}^{B}/F_{cs}$ to become too large. With a restriction of 1.5, the second group of terms would be positive whenever $t > 0.033$, or for all but extremely thin skin gages.

For the third group of terms

$$\left[\frac{1}{l_A}\left(\frac{1}{F_{cc}{}^{A}} + \frac{1}{F_{tu}}\right) - \frac{1}{l_B}\left(\frac{1}{F_{cc}{}^{B}} + \frac{1}{F_{tu}}\right)\right]$$

the spar cap compression allowable, F_{cc}, will generally be extremely high, since in a well-stabilized large spar cap even flange crippling near the compression yield stress level will not induce overall failure. Spar cap compression allowables of approximately 80 or 90 per cent of F_{tu} are not unreasonable. Similarly, since the tension surface must be designed for the critical sections, usually at a chordwise line of rivets attaching ribs or formers to the skin, the allowable tension stress must be modified for rivet factors. Nominal rivet factors are likewise in the order of 0.8 to 0.9 for such interpanel rib riveting. Therefore, it can be assumed with negligible error that $F_{tu} = F_{cc}$.

However, while there is a limitation upon $F_{cc}{}^{B}$ in relation to F_{cs} as described earlier, there is no such limitation upon $F_{cc}{}^{A}$; therefore, the following generalities can be conservatively assumed to exist:

$$F_{tu} = F_{cc}{}^{A} = 1.1F_{cc}{}^{B}$$

The third group of terms can be reduced, therefore, to

$$(1/F_{cc}{}^{B} \cdot l_A \cdot l_B)[1.82l_B - 1.91l_A]$$

Thus, this group of terms has positive values whenever $l_A < 0.95l_B$. Because spar caps that carry the entire bending moment are generally large in area, thus reducing their lever arms, and also as the usual chordwise locations of the spars are well forward or aft of the maximum depth point of the airfoil section, most conventional wing structures would be included in the above category.

It is therefore evident that each of the three groups of terms of Eq. (3) will, in most cases, be individually positive, the sum total indicating a definite weight advantage for design type B. Even in the exceptional cases of very thin skins coupled with light load, and thick flat airfoil sections with optimum spar location, the positive value of the first group of terms may well exceed the small negative values that could possibly exist in the remaining two groups. Thus, it can be seen that, for most design problems, the stringer type

of structure is the most efficient weightwise as well as generally the most practical.

Optimum Stringer Spacing

The limitations of stringer design, as well as its advantages, are evident also from the basic area equations. It is only for fairly thick skins that a minimum weight design is obtained by having such close stringer spacing that all of the skin is effective in compression. Even though for most structures a stringer type of design may be lighter than design type A, there is an optimum stringer spacing, and, in many instances, weight economy is lessened as a result of an increase in the number of stringers, despite the utilization of additional effective skin area.

From Eq. (2), the parameters involving stringer spacing and affecting weight are A_s and n. Therefore, the most efficient weight design is obtained when

$$A'' = n\left[A_s\left(1 - \frac{F_{cs}}{F_{cc}{}^B}\right) - 30t^2\left(\frac{F_{cs}}{F_{cc}{}^B}\right)\right] \qquad (4)$$

is an algebraic minimum, where the effects of additional stringers upon the other factors, l_B and $A_R{}^B$, can be assumed to be of second-order importance and therefore negligible. A weight advantage can thus be gained by reducing and adding more stringers when

$$(t^2/A_s) > 0.0333[(F_{cc}/F_{cs}) - 1]$$

a curve of which is plotted in Fig. 2.

For the thinner skin gages, where a wide stringer spacing may prove the most efficient weightwise, practical limitations of panel widths must be employed to prevent undue buckling or oil canning and also to retain the couple arm advantage of stringer-type design.

Rib Structure

There are two general categories of ribs employed in wing structures. The first is the primary load distribution rib, designed in every detail by the forces and reactions acting upon it. The other category includes those ribs and formers which are secondary in nature and whose functions can be outlined as follows:

(1) Distributing the air loads to the spars.

(2) Supporting and stabilizing the skin-stringer panels and reacting the wing flexural crushing forces.

(3) Retaining the airfoil shape and surface contour.

The bending stresses imposed upon ribs in conventional aircraft as a result of airloads are generally small; therefore, little or no variation in rib weight exists as a dependent upon rib spacing. The flexural crushing forces acting on the ribs are a function of stringer stress to the squared power while only linearly dependent upon rib spacing, as shown below.

$$P_{cr.} = \frac{MS_yA_s}{EI^2} = \frac{f^2A_s \cdot S}{E_y} \quad \text{(reference 2)}$$

Thus, large stringer stresses at close rib spacing may produce crushing forces upon the ribs equal to, or greater than, smaller stringer stresses at wide rib

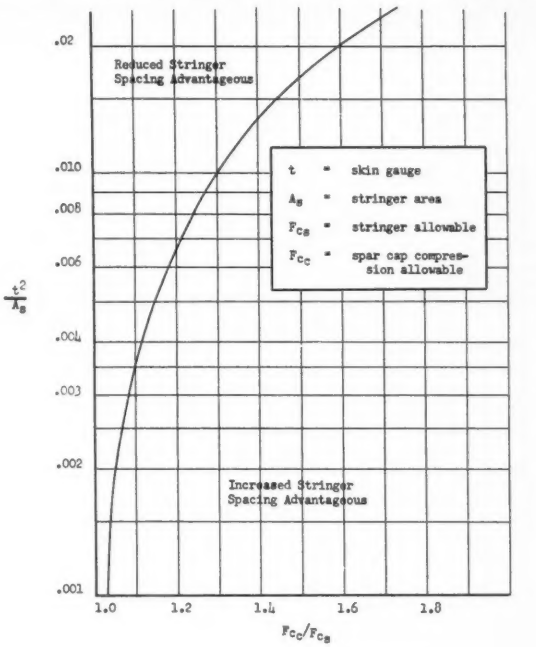


FIG. 2. Stringer spacing efficiency curve.

spacing. In practice, the crushing forces per stringer for all but very heavily loaded thin-winged aircraft are generally small enough so that moderate variations in rib spacing and consequently stringer allowables will not affect rib weight.

In addition, because the air load and crushing forces are mutually opposed on the upper surface of the wing for normal flight, and since the crushing forces on the lower surface are distributed along the rib because the skin is fully effective in tension, the sensitivity of rib weight to rib spacing is further reduced.

Importance of Rib Spacing

Comparatively little attention with regard to design analysis is generally paid these secondary ribs, yet their importance in affecting optimum weight design is far from negligible. They are frequently overlooked in design considerations because the web gages utilized are generally standardized minimums with little or no weight variation with rib or stringer spacing. This very fact, however, of insensitivity of air-load rib weight to rib spacing, is what is of extreme significance in the determination of a minimum weight design.

Quite often, the stress analyst and designer, in the pursuit of minimum structural weight, will attempt to obtain very high stringer column allowables in the belief that high allowables indicate less compression material needed, and, therefore, a lighter structure.

Unfortunately, however, the smaller stringer area is usually compensated for, and very often overcompensated for, by the greater amount of rib weight caused by the reduced rib spacing which provides the higher stringer allowables.

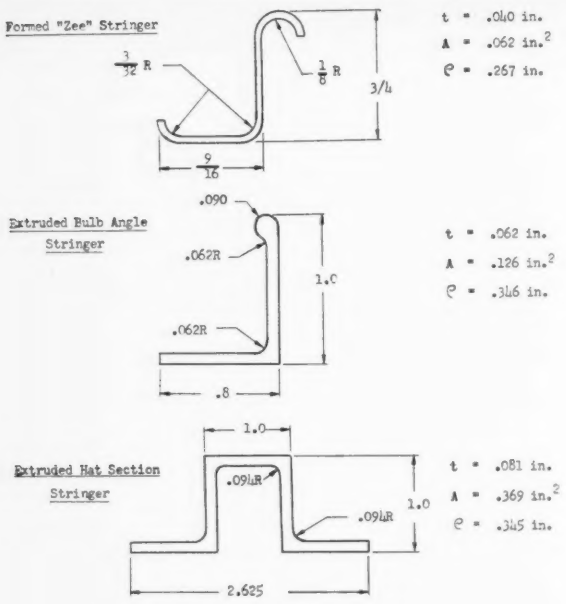


FIG. 3. Typical stringer types.

OPTIMUM RIB SPACING

The effective area that is dependent upon only stringer allowable and rib spacing from Eq. (2) is

$$A''' = \frac{V_R}{S} - n\left(\frac{F_{cs}}{F_{cc}}\right)(A_s + 30t^2) \qquad (5)$$

which should be kept to a minimum. For typical stringer types as shown in Fig. 3, it can be shown that minimum weight for all but heavy stringer design is often obtained with relatively large rib spacing, despite the reduction in F_{cs}.

Typical column curves for various stringer types are shown in Fig. 4.[5] Stringer end fixity coefficients are assumed to be 1.5, therefore,

$$l'/\rho = l/\sqrt{1.5}\rho$$

Minimum weight rib spacing is thus a function of the rib weight increase with large rib spacings as against the stringer weight decrease with smaller rib spacings and can be evaluated for any specific design problem. Even if loading and design conditions are such that equivalent structural weights are obtained with several rib spacings, the larger value is generally preferable. The correspondingly lower stresses will minimize problems of stress concentration, fatigue life, and permanent set, as well as result in smaller wing deflections, always a desirable feature.

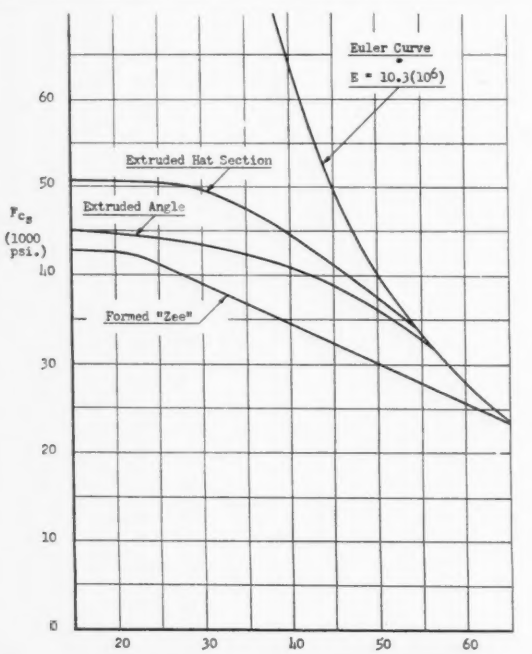


FIG. 4. Typical stringer column allowables.

Formed "Zee" Stringer Design

For light-gage formed stringers, used generally with fairly thin skins, relatively high compression allowables for close rib spacings are obtainable. Optimum rib spacing can be calculated with the following representations and assumptions:

Skin t = 0.032-in. 75ST material.

Spar cap allowable = 50,000 lbs. per sq.in.

Stringer spacing at approximately 6 in., n = $C/6$.

Ribs, for illustration purposes, are conservatively assumed fairly light, since a heavy rib structure would only indicate the benefits of larger rib spacing for optimum weight design; therefore, $V_R \approx 5t \cdot C = 0.160C$.

The stringer allowable curve for the critical area is represented by a straight line function,

$$\begin{bmatrix} S = 8.2 \text{ in.} \\ l'/\rho = 25.5 \\ F_{cs} = 41{,}000 \text{ lbs. per sq.in.} \end{bmatrix} \quad \begin{bmatrix} S = 20 \text{ in.} \\ l'/\rho = 61 \\ F_{cs} = 25{,}500 \text{ lbs. per sq.in.} \end{bmatrix}$$

$$F_{cs} = 51{,}800 - 1{,}313(S)$$

Eq. (5) can thus be rewitten as

$$A''' = \frac{0.160C}{S} - (n)\left(\frac{51{,}800 - 1{,}313(S)}{50{,}000}\right)(0.062 + 0.031)$$

$$= C\left[\frac{0.160}{S} + 0.000407S - 0.0161\right]$$

Minimum weight rib spacing is obtained by setting the derivative of this function with respect to S equal to zero.

$$\frac{d(A''')}{dS} = \frac{-0.160}{(S)^2} + 0.000407 = 0; \qquad S = 19.8 \text{ in.}$$

At a rib spacing of 19.8 in., F_{cs} = 25,800 lbs. per sq.in.; therefore, only 60 per cent of the maximum

stringer compression allowable is utilized, and yet minimum weight design would be attained. Such a large optimum spacing reflects the assumption of constant rib weight regardless of rib spacing, true only for light-airplane design where air loads and stringer loads to ribs are small. If formers are used with such stringers, however, the former weight can be expected to increase with larger rib spacings. For the above example, the former volume for illustration purposes is assumed to vary linearly as follows:

$$V_R' = 0.0064C(S + 10)$$

Eq. (5) would then be

$$A''' = \frac{0.0064C(S + 10)}{S} + 0.000407SC - 0.0161C$$

or

$$A''' = C[(0.064/S) + 0.000407S - 0.0097]$$

$$\frac{d(A''')}{dS} = \frac{-0.064}{(S)^2} + 0.000407 = 0$$

or $S = 12.55$ in. For this condition, where the former weight is assumed to increase 50 per cent for $S = 20$ in. over the value at $S = 10$ in., minimum weight would be attained at a rib spacing of 12.55 in. or where $F_{cs} =$ 35,500 lbs. per sq.in., only 83 per cent of the maximum allowable.

Extruded Bulb Angle Stringer

For the bulb angle shown, optimum rib spacing calculations can be demonstrated with the following assumptions:

Skin $t = 0.051$-in. 75ST material.

Spar cap allowable = 55,000 lbs. per sq.in.

Stringer spacing at approximately 5 in. or $n = C/5$.

Rib volume assumed constant at $4 \cdot tC = 0.204C$.

Eq. (5) can then be rewritten as

$$A''' = \frac{0.204C}{S} - \frac{F_{cs}}{55{,}000}\left(\frac{C}{5}\right)(0.126 + 0.078) =$$

$$C\left[\frac{0.204}{S} - 0.074(10^{-5})F_{cs}\right]$$

These calculations are shown in Table 1.

Minimum weight design for constant weight ribs is thus attained at a rib spacing of 17.5 in. or where $F_{cs} =$ 40,600 lbs. per sq.in., 89 per cent of the maximum stringer allowable. If the rib volume were assumed arbitrarily to increase with length of spacing as $V_R' =$ $0.0102C(S + 10)$, minimum weight would be obtained with ribs located every 14 in. and with $F_{cs} = 43{,}000$ lbs. per sq.in.

Extruded Hat-Section Stringer

For the hat-section stringer, used generally with heavy skins and located such that the skin is fully effective in bending, calculation of optimum rib spacing can be illustrated with the following assumptions:

Skin $t = 0.081$-in. 75ST material.

Spar cap allowable = 65,000 lbs. per sq.in.

TABLE 1

Minimum Weight Rib Spacing; Extruded Bulb Angle Stringer

S	ℓ'/ρ	F_{cs}	A'''/C Con. Rib Wt.	A'''/C Var. Rib Wt.
8.5	20.2	45,000	-.0093	-.0111
10	23.7	44,600	-.0126	-.0126
12	28.5	44,000	-.0156	-.0139
15	35.5	42,500	-.0179	-.0145 opt.
17.5	41.5	40,600	-.0183 opt.	-.0140
20	47.4	38,000	-.0179	-.128

TABLE 2

Minimum Weight Rib Spacing; Extruded Hat-Section Stringer

S	ℓ'/ρ	F_{cs}	A'''/C
10.5	25	50,500	-.0788
12.0	28.4	50,000	-.0798 opt.
14.0	33.2	48,700	-.0791
16.0	37.9	45,800	-.0741
18.0	42.7	43,000	-.0691
20.0	47.3	40,000	-.0634

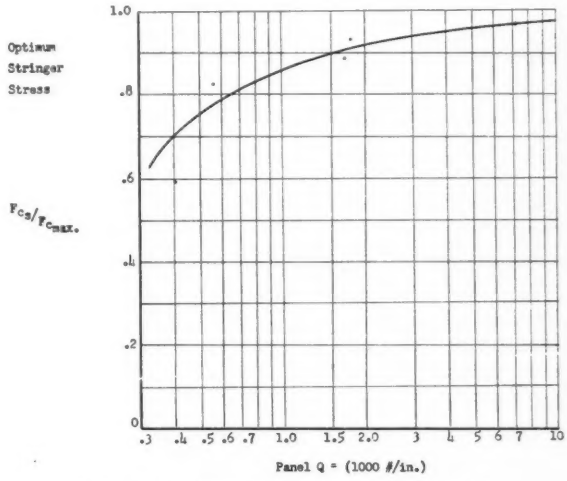


FIG. 5. Optimum design stringer stress ratios.

Stringer spacing for fully effective skin is 5 in., and, as n is the number of rivet rows and A_s is taken as half the section area ($A_s = 0.1845$ sq.in.), $n = C/2.5$.

For such heavy construction, rib weight variation with rib spacing cannot be neglected, and, therefore, the rib weight is assumed to increase as $V_R = 0.017C(S + 10)$.

Eq. (5) must be modified since the effective area between hat rivet lines is less than $30t^2$. Therefore,

$$A''' = \frac{V_R}{S} - (n)\left(\frac{F_{cs}}{F_{c_c}}\right)(A_s + 0.95t + 15t^2)$$

which can be reduced to

$$A''' = C[0.017 + (0.170/S) - 0.222(10^{-5})F_{cs}]$$

Rib spacing for minimum weight can be calculated as shown in Table 2. Optimum weight design is thus attained with rib spacings of 13 in., with the stringers developing 49,300 lbs. per sq.in. or 97 per cent of their maximum compression allowable.

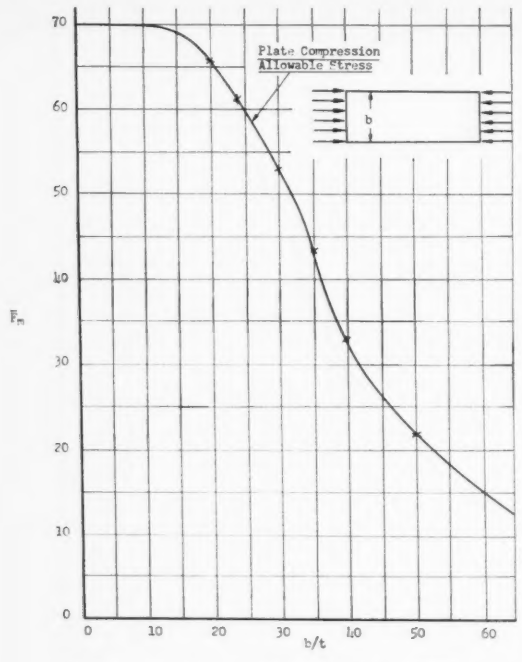


FIG. 6. Plate compression allowables—75ST.

The percentage of maximum compression or crippling allowable which is attainable in a stringer for minimum weight design is thus dependent upon the type of stringer employed and the panel load per inch upon the structure. Averaging the values previously obtained for the assumed rib weights and stringer spacings, a curve of optimum stress ratios versus loading can be obtained, as shown in Fig. 5.

MULTISPAR DESIGN

For such wing designs as lend themselves to the multispar type of structure by virtue of large axial loads per inch, minimum weight structure is attained by the optimization of the intermediate spar web thickness and the spar spacing.

Although the intermediate spars are capable of transmitting wing shear and torsional forces, their primary function is to support the surface skins under wing crushing and air-load pressures, since nominal design of the front and rear spars of the conventional structural box generally results in sufficient strength for primary shear-carrying purposes. Optimum design of these intermediate supporting spars, therefore, should be in the direction of the lightest spar structure capable of resisting the pressure forces, with thin stiffened spar webs or very light corrugations ideally suited for the purpose. The effective thickness or required area per inch of the intermediate spar, $t_{sp\text{eff.}}$, for the crushing forces per inch of

$$\frac{P_{cr.}}{S} = \frac{f^2A}{E_y} = \frac{(f)^2(bt + Ac)}{E(h_s/2)}$$

are

$$t_{sp\text{eff.}} = \frac{2(f)^2(bt + Ac)}{(F_{sp})Eh_s} \qquad (6)$$

Plate Compression Allowables

For conventional wing designs, the skin shears from wing torque can be considered as secondary effects in comparison to the magnitudes of the primary axial forces. In general, flight conditions producing large wing torsions, such as rolling maneuvers, result also in somewhat reduced wing bending moments; therefore, the combined effects are generally no more severe than the maximum axial load condition. For most designs, therefore, except for the root area of a swept-back wing where a component of the primary bending is converted to root torsion and where special panel allowable calculations for combined shear and compression must be made, the effect of shears upon the plate compression allowable can usually be neglected. Due to flexural bending of an actual wing surface, however, normal or crushing pressures will exist in conjunction with the compression loading and should be considered in the panel allowables.

The critical buckling stress for an axially compressed flat plate under various conditions of side and loading edge support has been the subject of considerable theoretical investigation. Typical buckling stress formulas take the form of

$$\frac{F_{cr.}}{\eta} = \frac{K\pi^2E}{12(1-u)^2}\left(\frac{t}{b}\right)^2 \quad \text{(reference 4)}$$

The maximum panel allowable $\bar{F}_m$ can be obtained from $F_{cr.}/\eta$ for any structural material.[4] The coefficient K is dependent upon the panel edge conditions, varying from 4.0[2] for all edges clamped and $a/b = \infty$, to 7.0[3] for sides clamped, loaded ends pinned, and $a/b = 2.1$. Conservatively assuming $K = 3.7$, and the parametric values of $E = 10.5(10^6)$ lbs. per sq.in. and $u = 0.3$. The variation of $\bar{F}_m$ with b/t for 75ST bare plate in conventional wing structure is given in Fig. 6.

The area per span $= bt + A_c + A_{sp}$, where A_c is the intermediate spar cap area and A_{sp} is the distributed area of the intermediate spar web per surface.

The force per span is $Q \cdot b = \bar{F}_m(bt + A_c)$; therefore, $b = \bar{F}_mA_c/(Q - \bar{F}_mt)$. Taking the number of spans as C/b and $A_{sp} = t_{sp\text{eff.}}(hs/2)$, the total area is

$$A_{tot.}{}^C = C\left[t + \frac{Ac + A_{sp}}{b}\right] = Ct + \frac{C(Q - \bar{F}_mt)}{F_mA_c}(A_c + A_{sp})$$

$$A_{tot.}{}^C = C\left[\frac{Q}{\bar{F}_m} + \frac{A_{sp}}{b}\right] \qquad (7)$$

For thin airfoils, the ratio of spar height to structural chord can be approximated as follows: Maximum airfoil thickness to aerodynamic chord ratio = 8 to 10 per cent; structural chord to aerodynamic chord ratio = approximately 50 per cent.

The average spar height, h_s, of a contoured thin wing is therefore approximately $0.16C$. The effective thickness of the spar web necessary to support the skin crushing forces will be dependent upon the skin thickness, varying approximately from $0.15t$ for thick skins to $0.20t$ for thin skins in practical design. The spar cap members are considered as effective compression material.

The usage of the multispar type of structure is obviously limited to skins of sufficient thickness such that the supporting spars will not be impractically close together.

Optimum Spar Spacing

The optimum spar spacing is dependent upon the variation of $\bar{F}_m$ with b/t and also upon the spar web area. The skin thickness

$$t = \frac{Q}{\bar{F}_m} - \frac{Ac}{b} = \frac{Q}{\bar{F}_m} - \frac{A_c}{t(b/t)}$$

Reducing the resulting quadratic equation,

$$t = \frac{Q}{2\bar{F}_m} + \frac{1}{2}\sqrt{\left(\frac{Q}{\bar{F}_m}\right)^2 - \frac{4A_c}{(b/t)}}$$

Calculations for Q = 10,000, 20,000, 40,000, and 60,000 lbs. per in. are presented in Table 3, based on conventional design assumptions for A_c and $A_{sp} = t_{sp}(h_s/2)$.

A cutoff line for minimum b/t values exists because of the spar cap area that can carry sizable percentages of the axial load at close spar spacing. This is especially true for relatively light loads per inch.

For example, for Q = 10,000 lbs. per sq.in., assuming A_c = 0.20 in.^{2} and A_{sp} = 0.17 in.^{2}, b/t values of less than 27 are impractical and inefficient, since

$$[(Q/\bar{F}_m)^2 - 4(A_c/b/t)] < 0$$

thus indicating the limitations of multispar structure for relatively light loadings. The information obtained from the tables can be summarized into design curves as shown in Figs. 7 and 8.

TABLE 3
Optimum Spar Spacing; Multispar Design

	b/t	$\bar{F}_m$	$Q/\bar{F}_m$	t	b	A_{Tot}/C
Q = 10,000#/in. A_c = .20 in.^{2} A_{sp} = .17 in.^{2}	27 30	56,500 53,000	.177 .189	.110 .142	2.97 4.26	.234 .229-Optimum
Q = 20,000#/in. A_c = .20 in.^{2} A_{sp} = .21 in.^{2}	14 16 18 20 24 30	69,200 68,800 68,000 66,000 61,000 53,000	.289 .291 .294 .303 .328 .377	.225 .238 .250 .265 .301 .359	3.15 3.81 4.50 5.30 7.22 10.77	.356 .346 .341-Optimum .343 .357 .397
Q = 40,000#/in. A_c = .35 in.^{2} A_{sp} = .34 in.^{2}	14 16 18 20 24 30	69,200 68,800 68,000 66,000 61,000 53,000	.578 .582 .588 .606 .656 .755	.531 .543 .553 .576 .633 .739	7.43 8.69 9.95 11.52 15.19 22.17	.624 .621-Optimum .622 .635 .678 .770
Q = 60,000#/in. A_c = .40 in.^{2} A_{sp} = .40 in.^{2}	12 14 16 18 20 24 30	69,500 69,200 68,800 68,000 66,000 61,000 53,000	.863 .867 .872 .882 .909 .984 1.132	.822 .831 .842 .854 .887 .967 1.220	9.86 11.63 13.47 15.37 17.74 23.21 36.60	.904 .901-Optimum .902 .908 .931 1.001 1.143

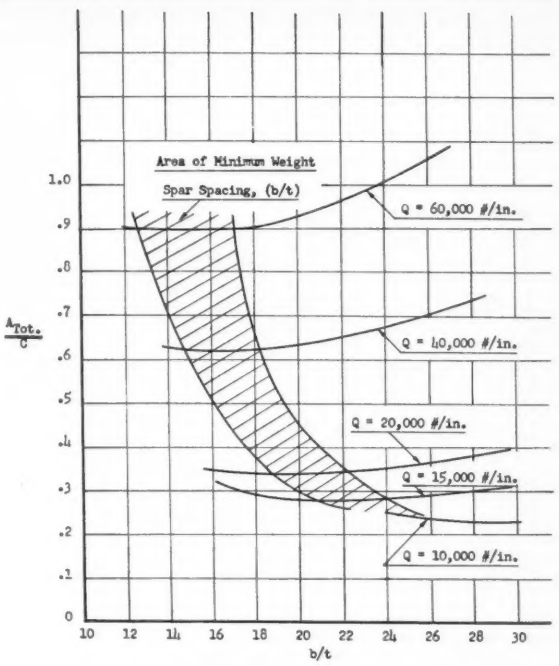


FIG. 7. Optimum spar spacing, multispar design area versus (b/t).

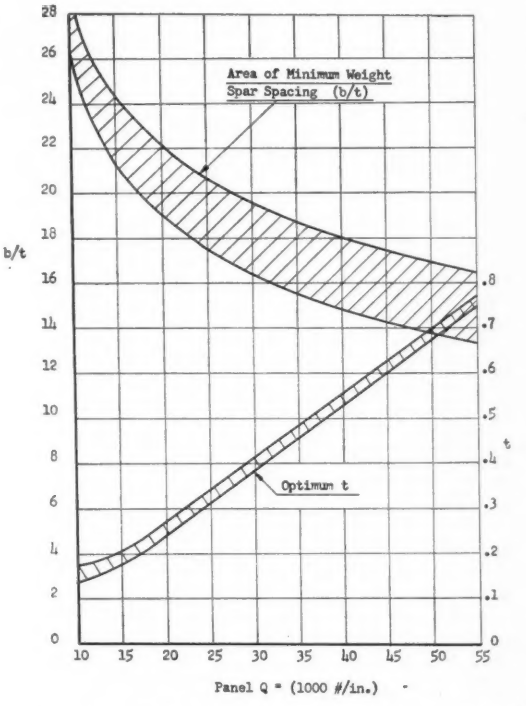


FIG. 8. Optimum skin thickness and spar spacing versus loading per inch, multispar design.

CONCLUSIONS

For an overall wing, optimum design is thus a compromise of many factors and variables. However, within the boundaries of airfoil size and shape set by

TABLE 4
Compression Area Calculations

Q #/in.	$A_{Tot.}$ C = 30 in.				
	Multi-rib Design	Multi-stringer Design			Multi-spar Design
		Formed "Zee"	Extruded Bulb Angle	Extruded Hat	
500	1.593	1.531			
1,000	1.808	1.803	2.226		
1,500	2.022	2.076	2.456		
2,000		2.349	2.687	2.879	
3,000		2.895	3.149	3.321	
4,000			3.610	3.762	
5,000			4.072	4.203	
10,000				6.409	6.87
20,000				10.821	10.23
40,000					18.60
60,000					26.97

aerodynamic considerations, or the requirements of specialized features of design such as ease of maintenance or fabrication and operational cost, there still remains a sizable area of possible design variation in which it is the problem of the stress analyst to achieve minimum weight without placing structural integrity in jeopardy. This can be accomplished for general wing designs utilizing stringers, quite often at relatively low stringer compression stresses, with attendant benefits in structural rigidity and long fatigue life. For heavily loaded skin surfaces where the advantages of multiple spar design are manifest, minimum weight design can be attained by the proper balance of intermediate spar spacing and effective thickness.

Design Selection Curves

Because of the many parameters and variables dependent upon actual wing geometry, optimum design selection curves can only be general in scope and can best be made with couple load per inch as an ordinate. The couple arm length between tension and compression surfaces, which is important in determining the optimum type of design, cannot be included directly in such curves, as it is dependent upon the airfoil size, thickness, and contour and is numerically determinable only for specific design problems. While the curves are therefore not directly comparative, slight adjustments in the Q load per inch can readily be made for the varying lever arms with different types of design. For example, with a given wing bending moment, the couple arms for types C, B, and A will decrease respectively, with proportionate increases in the values of Q. For this reason the apparent weight advantages of multistringer design relative to multirib design or multispar design relative to both of the other types will not be as apparent in the curves as the specific calculations for a given design problem would demonstrate.

The calculations for the design selection curves given below are based upon a structural chord width of 30 in. and can be made for any desired width or stringer and skin combination for which data are available. To facilitate demonstration of the method of design curve calculations, simplifying assumptions

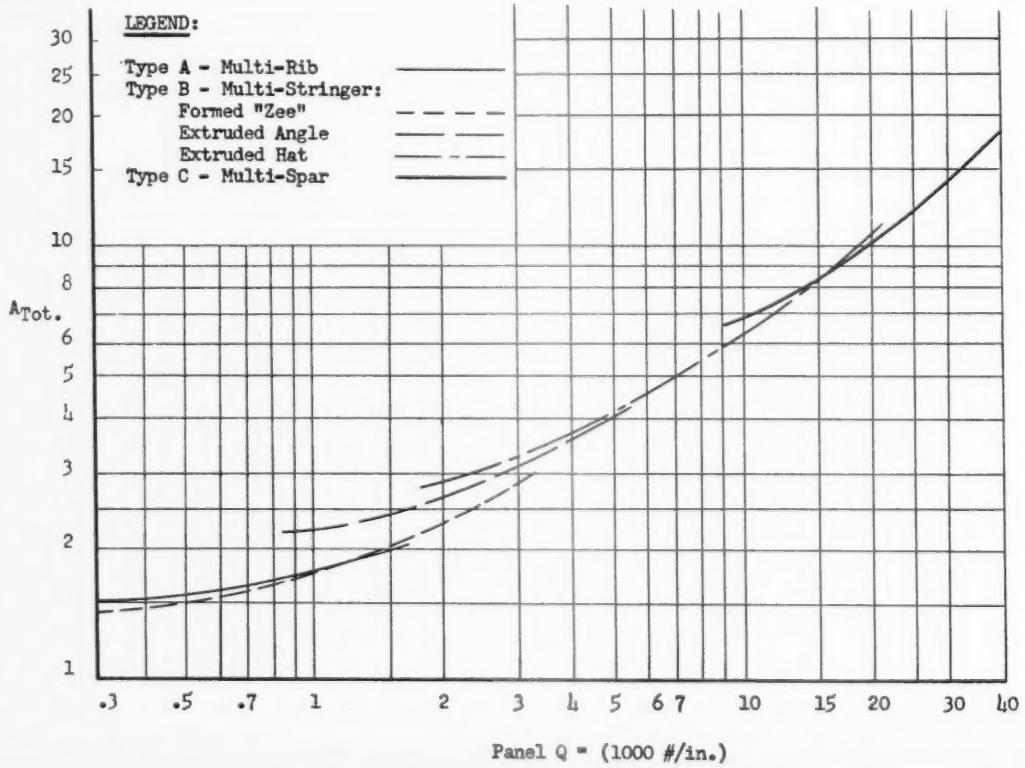


FIG. 9. Design selection curves, C = 30 in.

are made as required. The couple load P is taken as $M/l = QC$.

Multirib Design, Type A.—The total area is

$$A_{\text{tot.}}{}^{A} = \Sigma A_c + Ct + A_R{}^{A} = (QC/F_{cc}) - 60t^2 - Ct + A_R{}^{A}$$

Assuming $S = 10$ in. and $A_R = 5tC/S = 0.5tC$

$$A_{\text{tot.}}{}^{A} = (QC/F_{cc}) - 60t^2 + 1.5tC$$

For $t = 0.032$, and taking $F_{cc} = 70{,}000$ lbs. per sq.in.

$$A_{\text{tot.}}{}^{A} = (QC/70{,}000) + 0.048C - 0.061$$

Multistringer Design, Type B.—The total couple load area is

$$A_{\text{tot.}}{}^{B} = \frac{QC}{F_{cc}} - \left(\frac{F_{cs}}{F_{cc}}\right)(n)[A_s + 30t^2] + nA_s - 60t^2 + Ct + A_R$$

For 75ST spar cap material, F_{cc} is assumed at $1.5F_{cs}$ approximately, with a maximum limitation of 68,000 lbs. per sq.in.

Formed "Zee" Stringer Design

The optimum rib spacing is taken at 12.5 in., with $F_{cs} = 35{,}500$ lbs. per sq.in.

F_{cc} is assumed at 55,000 lbs. per sq.in.

Calculations are based on a skin thickness $t = 0.032$ in.

For the determination of optimum stringer spacing,

$$t^2/A_s = (0.032)^2/0.062 = 0.0165$$

which, with

$$F_{cc}/F_{cs} = 55{,}000/35{,}500 = 1.55$$

indicates a weight advantage in wide stringer spacing, see Fig. 2. For practical purposes, the stringer spacing will be taken at about 6 in., or $n = C/6$.

The effective rib area

$$A_R = \frac{V_R}{S} = \frac{0.0064C(12.5 + 10)}{12.5} = 0.0115C$$

$$A_{\text{tot.}}{}^{B(1)} = \frac{QC}{55{,}000} - \left(\frac{1}{1.55}\right)\left(\frac{C}{6}\right)[0.062 + 0.031] + \left(\frac{C}{6}\right)(0.062) - 0.062 + 0.032C + 0.0115C$$

$$= C[(Q/55{,}000) + 0.044] - 0.062$$

Extruded Bulb Angle Design

The optimum rib spacing is taken at 14 in. with $F_{cs} = 43{,}000$ lbs. per sq.in.

F_{cc} is assumed at 65,000 lbs. per sq.in.

The effective rib area

$$A_R = \frac{V_R}{S} = \frac{0.0102C(14 + 10)}{14} = 0.0174C$$

Calculations are based on a skin thickness of $t = 0.051$ in.

For optimum stringer spacing calculations, $t^2/A_s = (0.051)^2/0.126 = 0.0207$, which, for $F_{cc}/F_{cs} = 1.51$, indicates a weight advantage in reduced stringer spacing so as to utilize more effective skin in compression. The minimum stringer spacing, using the conception of $30t$ effective width of skin, would be $30(0.051) = 1.53$ in. As a practical minimum, a 2-in. stringer spacing will be assumed; therefore, $n = C/2$.

$$A_{\text{tot.}}{}^{B(2)} = \frac{QC}{65{,}000} - \left(\frac{43{,}000}{65{,}000}\right)\left(\frac{C}{2}\right)(0.126 + 0.078) + \left(\frac{C}{2}\right)(0.126) - 0.156 + 0.051C + 0.0174C$$

$$= C[(Q/65{,}000) + 0.064] - 0.156$$

Extruded Hat-Section Design

The optimum rib spacing is 13 in. with $F_{cs} = 49{,}300$ lbs. per sq.in.

F_{cc} is assumed limited to 68,000 lbs. per sq.in.

The effective rib area $A_R = 0.017C/S(S + 10) = 0.030C$.

Calculations are based on a skin thickness $t = 0.081$ in.

Because of its thickness, all the skin will be fully effective in compression for stringer spacings of approximately 5 in. or less. A 5-in. spacing is assumed. For convenience in calculations, the stringer area is taken as half the section area in conjunction with each row of rivets. Therefore, $A_s = 0.1845$ sq.in. and $n = C/2.5$.

$$A_{\text{tot.}}{}^{B(3)} = \frac{QC}{F_{cc}} - \left(\frac{F_{cs}}{F_{cc}}\right)(n)(A_s + 0.95t + 15t^2) + nA_s - 60t^2 - Ct + A_R$$

$$= \frac{QC}{68{,}000} - \left(\frac{49{,}300}{68{,}000}\right)\left(\frac{C}{2.5}\right)(0.1845 + 0.077 + 0.098) + \left(\frac{C}{2.5}\right)(0.1845) - 0.393 + 0.081C + 0.030C$$

$$A_{\text{tot.}}{}^{B(3)} = C[(Q/68{,}000) + 0.081] - 0.393$$

Area calculations based on the above assumptions for all types of structures considered are shown in Table 4. Typical design selection curves for the types of structures considered for varying couple loads per inch are presented in Fig. 9.

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[3] Timoshenko, S., *Strength of Materials, Part II,* 510 pp.; D. Van Nostrand Company, Inc., New York, 1941.

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Afterburners—Are They Worth While?

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Douglas Aircraft Company, Inc.

SUMMARY

Recent concern over the rising cost of an adequate air force has provided an impetus and a challenge to aircraft designers to consider carefully each step in the design of every aircraft. Since the power plant plays a major role in this design, the decision to use a certain power plant warrants considerable attention. At the present stage of military aircraft development and with the advent of the afterburning principle, the turbojet seems the most suitable power plant to consider. The question then arises: Which is the better to use—the turbojet with or without afterburning?

A general analysis is made of the problem for fighter aircraft, based on current data available on engine design and performance and some basic aircraft design parameters. The results of the analysis indicate that, for a typical fighter with a design maximum level flight Mach Number of 1.5 at 35,000 ft. and a given military load, the power-plant configuration resulting in the lesser gross weight, and hence cost, is the basic engine without afterburning.

INTRODUCTION

STUDY OF THE PROBLEMS of weight, size, and cost of current and projected military aircraft and of the attendant problems of economy and logistics during the past few years has emphasized the growing need for exacting scrutiny of every phase of aircraft design. This is a challenge to engineering skill and design which must be met successfully, if we are to have the aircraft we need for superiority in the air without a strained economy. Since the power plant plays a major role in determining size and weight of an aircraft, the importance of choosing the correct power plant to meet the design requirements is obvious.

As the afterburner is essentially a ram-jet engine attached to the basic turbojet, the afterburner thrust varies considerably with forward speed. As the forward speed is increased, the afterburning configuration becomes a more efficient thrust-producing device (Fig. 1). For the increasing speed requirements of current and future fighter aircraft, then, the afterburning engine provides a means of increased flight thrust without increased size (frontal area) but still retains the more desirable low-speed characteristics (with afterburner off) of the basic turbojet, such as essentially constant thrust with air speed for a given throttle setting and favorable specific fuel consumption.

Any consideration of a power-plant unit should logically be based on a comparison of the smaller afterburner-equipped engine and the larger unaugmented engine, or possibly multiple units of smaller engines, for a given set of performance and military load specifications.

In the interest of minimizing weight and cost and increasing the overall efficiency with which the combat aircraft is to accomplish its mission, the question often arises as to which power plant is better—the engine with the afterburner or the engine without the afterburner.

For each particular application or set of design requirements a detailed study is normally made with engines contracted for or under development. The result of the study is an airplane configuration whose design is often compromised as a result of conflicting design requirements of military load, performance, engine availability, and aircraft size and cost. The application of the results to future aircraft design problems is doubtful and is usually inadequate to answer the general question or emphasize the basic problem: are afterburners worth while? Should considerable attention be given to developing afterburner-equipped engines?

Because the results of these detailed design studies are insufficient to answer the general question, an analytical approach will be made in an attempt to simplify and possibly generalize the aircraft design parameters upon which the choice of an engine with or an engine

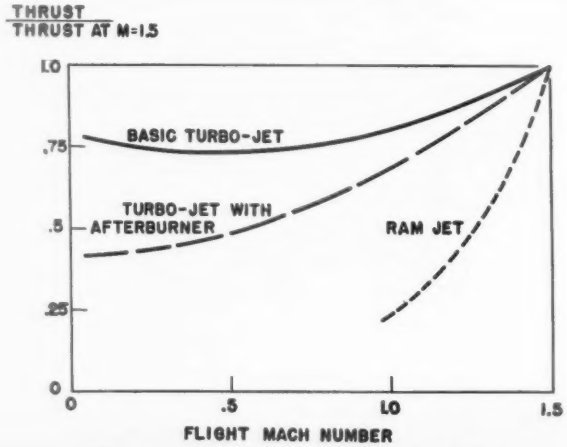

FIG. 1. Typical engine thrust characteristics.

Presented at the Propulsion Session, Annual Summer Meeting, IAS, Los Angeles, July 15–17, 1953.

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without afterburning could be made. Current and projected engine design and performance characteristics will be utilized within the limits of unclassified security information.

Design Requirements

The selection of the better power plant, the one with or the one without afterburning, is based on the airplane configuration of lower gross weight which fulfills the prescribed set of design requirements. For this study these design requirements are: (1) a maximum stabilized level flight speed of $M = 1.5$ at 35,000 ft., (2) a specified radius of action or combat radius, and (3) a military load or pay load of 4,000 lbs.

The first requirement is an arbitrary selection of a potential high-speed requirement for present and projected aircraft designs. The attainment of sonic speed by operational aircraft appears to be not too far in the future and, hence, is, from a design standpoint, no longer of much interest. In the higher Mach Number range ($M = 2$), any consideration of an optimum power plant would include a study of a ram-jet configuration. A Mach Number of 1.5, then, offers a point of particular interest in current design work and is consequently an opportune speed to use in analyzing the problem of which turbojet configuration is the better—the one with or the one without afterburning.

The second requirement, the combat radius, is not specified in terms of miles, since the object of this analysis is not only to determine the better power plant for a given radius of action but also to determine whether this power-plant configuration is independent, to some degree, of the actual radius. The combat radius is simply defined here as a percentage of the distance covered in a maximum-range cruise, after fuel allowance is made for a combat period at maximum thrust; this is covered in detail in the next section.

The third requirement is that the aircraft carry a specified military load. The basic configuration studied is to have a 4,000-lb. military load; however, the effect of alternate military loads on the results is also investigated.

Note that other potential performance requirements such as take-off and climb are not specifically considered. In order to keep the analysis completely general and independent of wing plan form or geometric characteristics, it is felt that this is appropriate and will not affect the results or applicability of the results by any substantial amount. A qualitative analysis of the relative take-off and climb performance for the afterburning and nonafterburning configurations is made in a later section.

Design Parameters

The combat radius is defined as a percentage of the turbojet maximum range where the maximum range is given by

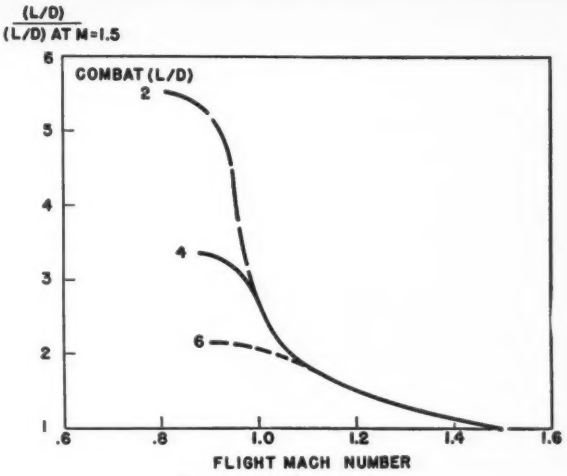

Fig. 2. Lift/drag ratio.

$$R = \frac{a}{c}\left(M\,\frac{L}{D}\right)\log_e \frac{1}{1 - (W_F/W_0)}$$

where

R = range (nautical miles)
a = speed of sound (knots)
c = cruise specific fuel consumption (lbs. of fuel per lb. of thrust)
$[M(L/D)]$ = Mach Number times lift/drag ratio for cruise
W_F = cruise fuel = total fuel less combat fuel (lbs.)
W_0 = take-off weight (lbs.)

The radius is now defined as $r = 0.4R$, where r = radius (nautical miles).

This means that the equivalent of approximately 20 per cent of the possible maximum range fuel is allowed for take-off, climb, landing, and reserve, over and above the separate fuel allowance made for the combat period. The combat fuel allowance is the sum of two items—the fuel required to accelerate from the approximate climb speed to 95 per cent of the maximum speed ($M = 0.95 \times 1.5 = 1.425$) at 35,000 ft. and the fuel used for a 15-min. combat period at the maximum speed. For the type of airplane configuration and maximum speed considered, a fairly representative climb speed of $M = 0.9$ is used throughout the study. The acceleration period is considered important in a study of this type and is included here to account for the significant difference in thrust variation with speed between the afterburning and nonafterburning engines. Considering the variation in specific fuel consumption with speed to have only secondary effects, then, with the postulated variation of thrust with speed at 35,000 ft. as previously shown in Fig. 1 and the variation of lift/drag ratio as shown in Fig. 2, the fuel required to accelerate can be determined, once the weight and specific fuel consumption are known. It is likely that the cruise altitude will be above 35,000 ft. (and hence

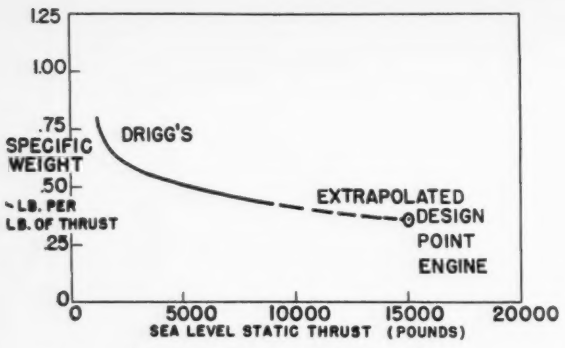

FIG. 3. Design engine characteristics.

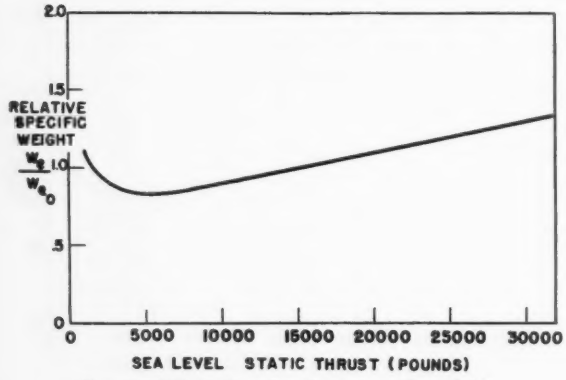

FIG. 4. Effect of engine size on specific weight.

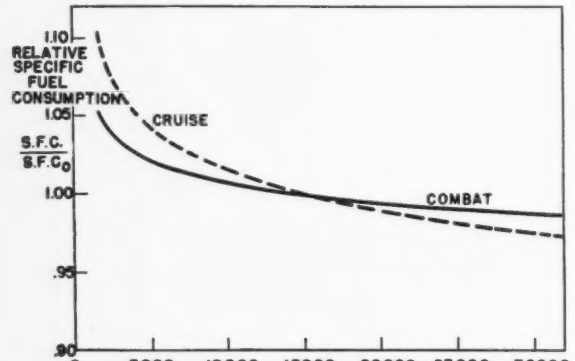

FIG. 5. Effect of engine size on specific fuel consumption.

a = 575 knots) and that a typical value for $[M(L/D)]$ would be 10. The radius equation then becomes

$$r = \frac{2{,}300}{c} \log_e \frac{1}{1 - (W_F/W_0)}$$

The drag and structural weight are dependent to a great extent upon the particular design and designer. For this study, the basic configuration has a structural-weight/gross-weight ratio of 0.4 and a combat lift/drag ratio of 4 at M = 1.5 at 35,000 ft. These are independent of aircraft size. The effects of other values of each of these parameters on the results of the study are also considered. Here again, to keep the study completely general, the wing plan form and geometry are not specified. This allows the actual values of both the aerodynamic and structural design parameters to rest with the individual designer's ingenuity and the "state of the art" to which the engineering team has advanced.

The one remaining and most important item to consider in order to find the solution to the power-plant problem is the design and performance of the engine or power plant. First of all, since the centrifugal-flow engines are of little interest at present, the basic turbojet engine considered is the typical axial-flow compressor type. An extrapolation of the trend curves shown in reference 1 to an arbitrary point 5 years from now gives a basic design point engine of 15,000 lbs. sea-level static thrust (unaugmented) (Fig. 3). The corresponding figure for specific weight based on the sea-level static design point is 0.36. The effects of engine size on the specific weight and specific fuel consumption are shown in Figs. 4 and 5. These figures are based primarily on the thorough study by Moyes and Pennington[2] but are modified to some degree for the smaller size engines to account for differences in British and American design practices in such things as strength, tolerances, and accessories.

How does adding an afterburner affect the specific weight and specific fuel consumption? There appear to be almost as many answers to this question as might be desired, since the afterburner configuration is quite flexible and sensitive to variations in numerous basic engine and flight design parameters. The published additional weight attributed to the afterburner has varied from 10 per cent[3] to 30 per cent[4] of the basic engine weight. Since continued development should improve this weight picture, the afterburning-engine specific weights are based on the lower value shown above (10 per cent) and based on the sea-level static thrust with the afterburner inoperative. (As the results show later, even this apparently favorable approach to afterburning-engine weights has little significance.)

The afterburner performance is also extremely flexible, and the augmentation and the corresponding increase in fuel consumption are functions of many design variables of the basic engine, the afterburner configuration itself, altitude, and forward speed. Unfortunately, there are few data published on afterburning performance. The following assumptions are made with regard to basic engine and afterburning performance for the design-point engine.

(1) *For the nonafterburning engine:*

(a) Sea-level static thrust is 5/3 of the maximum thrust at M = 1.5 at 35,000 ft.

(b) Specific fuel consumption for maximum thrust at M = 1.5 at 35,000 ft. is 1.1.

(c) Specific fuel consumption for cruise thrust, speed, and altitude is 1.00.

(2) *For the afterburning engine:*

(a) Sea-level static thrust with afterburner inoperative is 3/4 of the maximum thrust with afterburning at $M = 1.5$ at 35,000 ft.

(b) Specific fuel consumption for maximum thrust with afterburning at $M = 1.5$ at 35,000 ft. is 2.2. (This corresponds to a specific fuel consumption based on added afterburner thrust of approximately 4.5.)

(c) Specific fuel consumption for cruise thrust, speed, and altitude is 1.03 (based on an arbitrary 3 per cent increase over nonafterburning specific fuel consumptions to allow for losses associated with the flame holder, etc.)

Only single-engined configurations are considered in this study. This should not affect the results to a great extent, however, since both the afterburning and nonafterburning configurations could be optimized and would probably yield the same relative comparison but at different gross weights and/or radii. Furthermore, any more than one power-plant unit per aircraft should logically entail a design layout for arrangement, and this in turn would involve wing plan form, geometry, etc. The design simplification that is used in the study should be emphasized once again.

General Procedure

With the information previously given and the additional details below, the solution of the radius problem is fairly straightforward. The general procedure is as follows:

(1) For the specified military load and structure/gross-weight ratio, the take-off weight is allowed to vary through the weight range of interest.

(2) The take-off weight is defined as the sum of the military load, structural weight, fuel and fuel-system weight, and power-plant weight, and hence from (1), the sum of the fuel-system and power-plant weights can be determined.

(3) For a given combat lift/drag ratio and defining the combat weight equal to the take-off weight less 50 per cent of the total fuel weight, the drag or thrust can be determined. This permits obtaining the correction for engine size to the design-point specific weight and specific fuel consumption from Figs. 4 and 5, respectively.

(4) From (3) the power-plant weight can be found. (Both the afterburning and nonafterburning engines are installed for a weight of 10 per cent of the basic engine weight.)

(5) From (2) and (4) the fuel and fuel-system weight can now be determined. Based on a typical fuel-system weight of 1 lb. per gal. of fuel, the total fuel available is also determined.

(6) Since the total combat fuel is determined once the combat weight and specific fuel consumption are known, the fuel available for cruising flight and, hence, the combat radius can be determined.

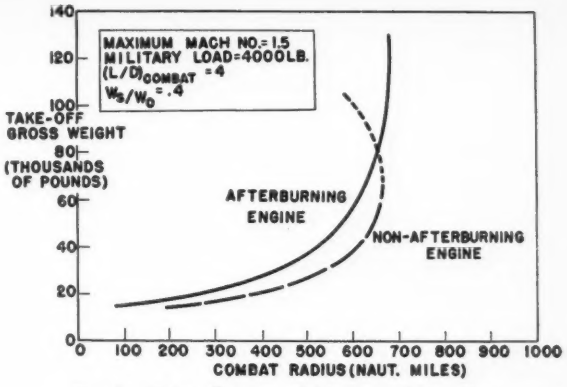

FIG. 6. Take-off gross weight vs. combat radius.

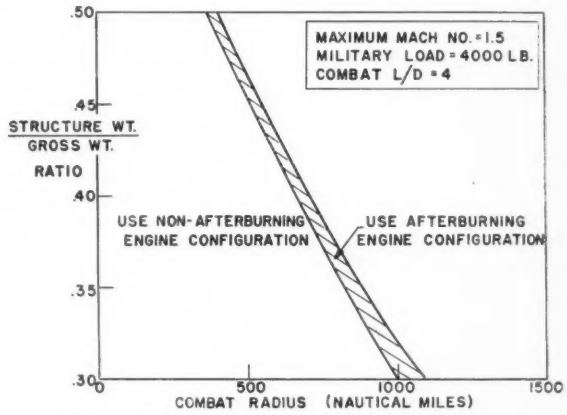
MAXIMUM MACH NO. = 1.5
MILITARY LOAD = 4000 LB.
COMBAT L/D = 4
STRUCTURE WT. / GROSS WT. RATIO
USE NON-AFTERBURNING ENGINE CONFIGURATION
USE AFTERBURNING ENGINE CONFIGURATION
COMBAT RADIUS (NAUTICAL MILES)

FIG. 7. Effect of structural-weight/gross-weight ratio.

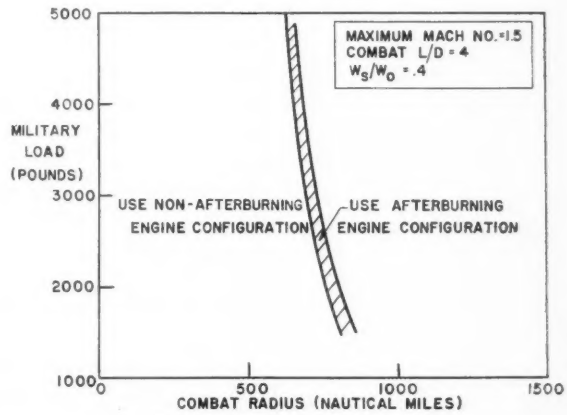

FIG. 8. Effect of military load.

Discussion of Results

Fig. 6 shows the take-off gross weight with and without afterburning, for the basic configuration as a function of the combat radius. The take-off gross weight of the afterburning-engine configuration for essentially the entire range of radii covered is higher by a substantial amount than the gross weight for the nonafterburning configuration for the same radius. This is due primarily to the high fuel consumption of the afterburning engine at maximum power; the results show that the lighter augmented engine is not suf-

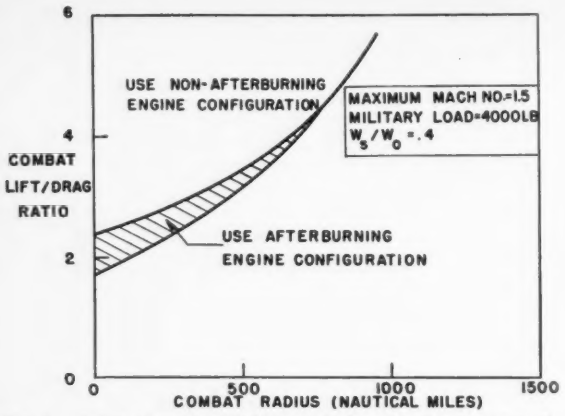

FIG. 9. Effect of combat lift/drag ratio (combat time = 15 min.).

ficiently light to offset the fuel requirement for combat. This is true until an unrealistic fighter gross weight of approximately 60,000 to 80,000 lbs. or a radius of approximately 670 nautical miles is reached. At this point, the maximum radius of the nonafterburning-engine configuration is attained. It is particularly significant in this figure that the magnitude of the differences in take-off gross weight appears to be more than could possibly be saved even in a detailed layout for the afterburning-engine configuration.

The relative comparison of afterburning and nonafterburning power plants is, of course, dependent upon the military load, combat lift/drag ratio, structural weight, and combat radius definition, as well as the assumptions used in defining those items. Consequently, each of these was allowed to vary independently in order to evaluate its individual effects on the point in question. The results are shown in Figs. 7–11 in the form of the combat radius for which each particular engine configuration results in the lower gross weight, as a function of the design parameter involved. The magnitude of the structural weight and military load as shown in Figs. 7 and 8 appears to have little effect on the results obtained for the basic configuration. This small effect is due primarily to the fact that the changes in either of these parameters affect both the nonafterburning and afterburning configurations in the same manner and by approximately the same reduction in fuel available (or radius) at the same gross weight.

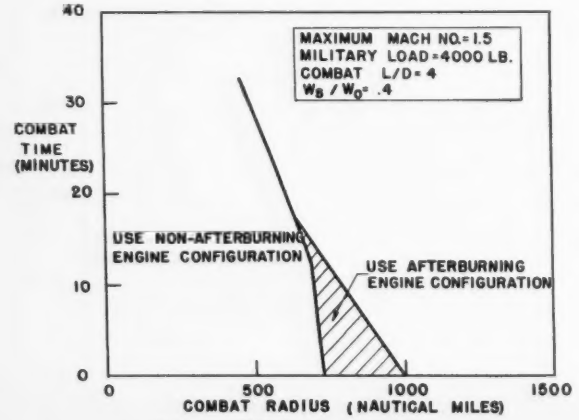

FIG. 10. Effect of combat time.

The combat lift/drag ratio has a significant role in determining the better power plant (Fig. 9). As the combat lift/drag ratio decreases from a value of approximately 3, the afterburning-engine configuration permits the attainment of a given radius at a lower gross weight than does the nonafterburning-engine configuration. This is due primarily to the comparatively large engine weights for the nonafterburning-engine configurations at the low lift/drag ratios.

As expected, the comparison changes rapidly with the time allowance at maximum power—the combat time. The effect of a change in the combat time, or combat fuel requirement, is shown in Fig. 10. (The combat time shown on this figure is the time at maximum speed—i.e., it does not include the acceleration allowance.) As the combat time is either increased or reduced from the 15 min. considered for the basic configuration, the nonafterburning configuration results in the lower gross weight, except for a relatively small range of radii.

Both the lower combat lift/drag ratios and the lower combat times, as shown in Figs. 9 and 10, indicate that the afterburning-engine configuration would result in a lower gross weight for a given radius within a certain range of the design parameters. Fig. 11 shows the combined effect of a reduction in the combat lift/drag ratio and a reduction in the combat time to 5 min. Except for radii of approximately 300 nautical miles or less at a combat lift/drag ratio of 3, the afterburning-engine configuration results in the lower gross weight for all radius requirements at a lift/drag ratio of 3 or less. For combat lift/drag ratios higher than 3, the nonafterburning-engine configuration results in the lower gross weight.

A few comments on the more important limitations in the study are now considered. First of all, no consideration is made of the possible differences in powerplant installations resulting from the use of the afterburning or nonafterburning engines, such as the relative size of the two and corresponding changes in fuselage or wing structure to accommodate them. Along the same line, no consideration is made of the relative design and space problems of straight-, swept-, and delta-wing configurations for the same lift/drag ratio characteristics. Other potential performance requirements such as take-off and climb are not specifically considered. In the method of analysis used, the stalling speed at the same take-off weight is considered constant, but no further consideration is given to take-off performance requirements. One point is mentioned here—for the same take-off weight, the sea-level static thrust for the afterburning-engine configuration is less than that of the nonafterburning-engine configuration; and, consequently, with the same stalling speed, take-off performance would be poorer for the afterburning-engine configuration. The same relative situation

exists when climb performance is considered. Here again, because of the relatively lower thrust at forward speeds other than at the design point at $M = 1.5$, the afterburning-engine-configuration performance will be poorer. In order to keep the analysis completely general and independent of wing plan form or other geometric characteristics it is believed that it is appropriate not to consider these additional performance items and that the general results obtained are not unduly compromised.

Concluding Remarks

Based on the results of this study, some general conclusions can be drawn with application to the design of turbojet-fighter-type aircraft. It can be concluded that the combat lift/drag ratio is the one parameter that is most important in determining whether the afterburning-, or nonafterburning-engine configuration results in the lower gross weight for a fighter aircraft.

Since the combat time and combat radius are extremely important parameters, two types of fighter aircraft are considered—the interceptor fighter, which would probably have a short combat radius of approximately 100 to 200 nautical miles and a combat period of the order of 5 min., and the escort fighter, which would probably have a combat radius of the order of 300 to 500 nautical miles and a combat period of approximately 15 min. For a combat lift/drag ratio of the order of 3 to 4 or higher, the nonafterburning-engine configuration would result in the lower gross weight for both the interceptor fighter and the escort fighter. For a combat lift/drag ratio of the order of 2 to 3, the afterburning-engine configuration would result in the lower gross weight for both the interceptor fighter and the escort fighter.

It is suggested that, if additional studies of this nature were made for other combinations of fixed design requirements, the results of these studies would show a fairly well-defined set of other boundary conditions that would limit the use of the afterburning or nonafterburning engines. Furthermore, if these studies were based on anticipated design and performance requirements of future fighter aircraft, an indication would be obtained of the engine size on which continued development of both the basic turbojet and turbojet-plus-afterburner should be emphasized.

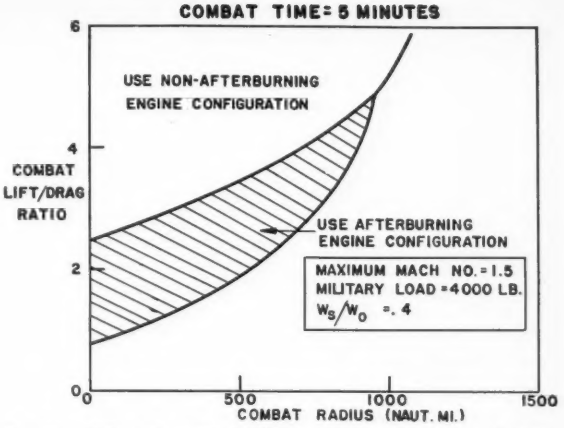

Fig. 11. Effect of combat lift/drag ratio (combat time = 5 min.).

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Design of the Hiller HJ-1, YH-32 Helicopter

HARVEY HOLM*
Hiller Helicopters

Design Evolution

The basic design of the Hiller-Hornet was evolved approximately 3 years ago, starting primarily as an engine development program. At that time, Hiller Helicopters, feeling that one future course for helicopter development was certainly in the direction of tip power, began work to develop a satisfactory ram-jet engine suitable for rotor tip mounting. The development of tip-mounted power plants to eliminate antitorque requirements, complex engine installations, and large power transmission systems was felt to be a major step in the direction of much to be desired helicopter simplification. Previous work with pulse-jets, both valved and sonic, had indicated that considerable mechanical trouble was likely to be encountered in this field, and it was thus decided to concentrate on the ram-jet engine type even though the fuel flow rates then quoted for subsonic ram-jets were little short of shocking.

The program started on a minimum basis with the manufacture of several prototype engines for test work and with the installation of an engine test facility, including a static stand and a small whirl stand, on the Company property in Palo Alto, Calif. Initial tests proved successful, and it was soon decided that a "flying test stand" was needed to test more adequately these rapidly evolving ram-jet engines. This "stand," shown in Fig. 1, was built up and first flown in August, 1950. As a helicopter, it represented the utmost in simplicity, having a rudder for directional control operated by "tiller" action of the collective stick, an overhead cyclic stick, a transmission consisting of three "V" belts driving a fuel pump, and a completely open cockpit. As a ram-jet test stand, however, it was quite satisfactory, and the majority of the development and tests for the next 2 years took place on this and subsequent ships (two more similar models were built within the next few months).

These three ships, in addition to acting as engine test stands, also proved the basic design of the helicopter, and, when the military evaluation version was officially dubbed the HJ-1, these machines were classified by the Company as the XHJ-1 ships.

Presented at the Helicopter Design Session, Annual Summer Meeting, IAS, Los Angeles, July 15–17, 1953.

* Project Engineer.

Design of the Evaluation Model

These test ships have now developed into the HJ-1, YH-32 class helicopter, as shown in Fig. 2. This model, while in some ways considerably changed from the original XHJ-1 version, still retains many of the design features developed during the early test period. Changes made in the conversion of the evaluation version have been predicated, for the most part, on the results of previous experience and on suggestions by military personnel. The major aim in all cases has been to maintain the simplicity that we believe to be possible with this style helicopter.

Engines

As an example of the simplification gained using this type of power plant, a cutaway view of the engine shown in Fig. 3 pictures the entire installation. In the interest of holding the overall length of the engine to

Fig. 1. Flying test stand—Hiller model XHJ-1.

Fig. 2. Hiller model HJ-1, YH-32 helicopter.

a minimum, all components have been held as short as possible. The fuel spray nozzle, pointing forward, is located just inside the inlet. The diffuser is short with a rapid expansion rate, and the flameholder is located well forward of the engine midpoint. The burning section and the short nozzle complete the engine.

This engine is manufactured from Inconel X, a high-temperature nickel-base alloy that is well suited for this use but which presents some manufacturing problems in forming and machining. The major development problems to date, in addition to manufacturing techniques, have been with starting and reignition from an operational point of view and with flameholder life from a structural point of view. These problems have been, to a large extent, overcome at the present time and will be finally corrected prior to engine certification.

Rotor System

The engines are mounted on either end of the rotor blades by means of two flush bolts. The rotor blades themselves are also manufactured by Hiller and are of an all-metal riveted and bonded construction. Blades of this type were used on the XHJ-1 ships and were satisfactory. The HJ-1, YH-32 blades have only minor modifications over these test blades, and static tests to date have shown satisfactory margins of safety. No fatigue tests have yet been completed.

The rotor system is generally similar to other Hiller models, the Hiller Rotor-Matic control, of course, taking a major part. The isolation of the rotor system is accomplished by a Lord Mount as shown in Fig. 4. This installation is again identical with that previously tested on the XHJ-1 model.

Cockpit Arrangement

Fig. 5 shows the cockpit arrangement. This is one of the major changes made in the military version from the test ships. The overhead stick has been exchanged for a floor stick; the tiller action of the collective stick has been replaced by rudder pedals; the cockpit width and length have been increased; and the seating arrangement has been improved. This cockpit is now in conformity, except for width, with the standard helicopter cockpit from the *Handbook of Instructions for Aircraft Designers*. The instrument panel, shown in the inset in Fig. 5, indicates again the simplicity of the ship. Only six instruments are required.

This ship is designed to be flown as a single-place ship, as a two-place ship with dual controls, and as a litter-

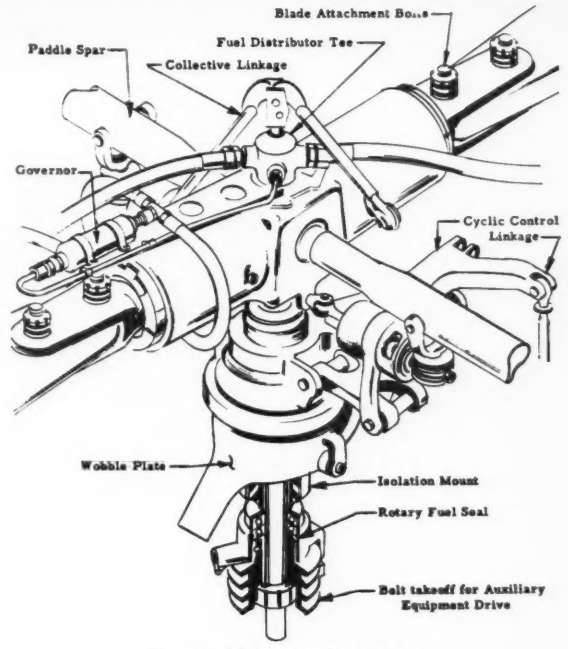

FIG. 4. Main rotor installation.

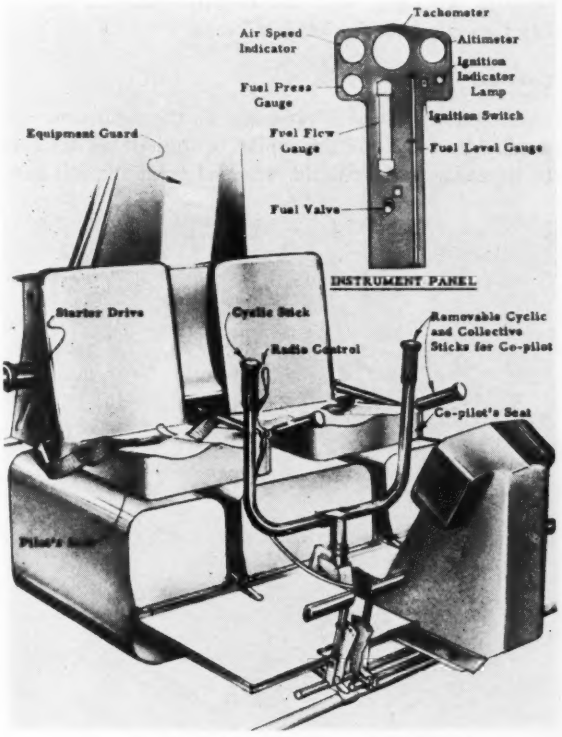

FIG. 5. Cockpit arrangement—dual control.

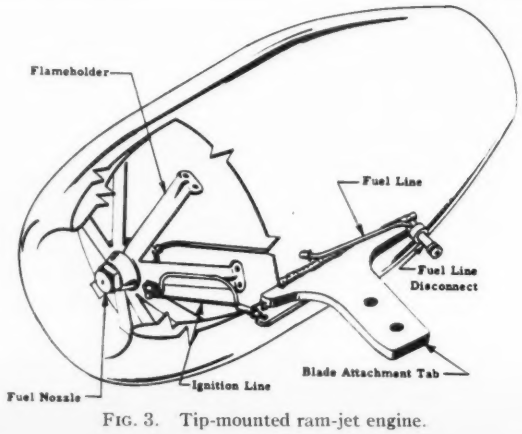

FIG. 3. Tip-mounted ram-jet engine.

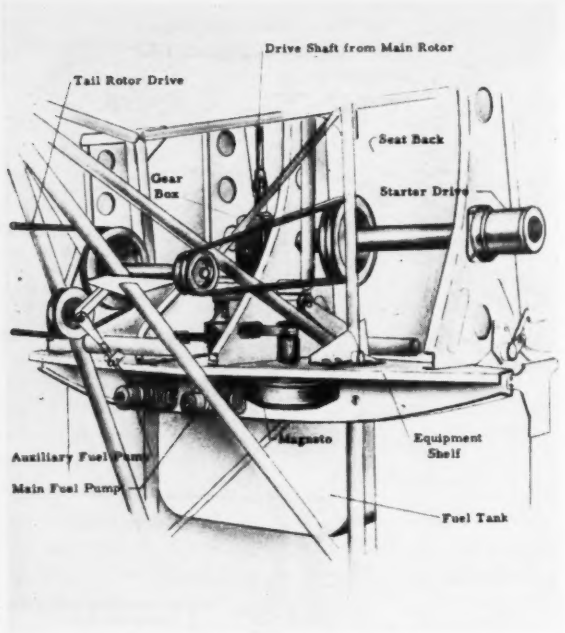

FIG. 6. Auxiliary drives installation.

bearing helicopter with the canopy removed and the litter installed on the left-hand seat.

Controls

The pilot position is normally on the right side, and the flight controls for the copilot or student are designed to be easily installed and removed from the left-hand seat position. The controls used with this model are conventional, being actuated by push-pull rods in the cyclic and collective systems and by cables in the tail rotor system. A conventional twist-grip throttle is located on each collective stick.

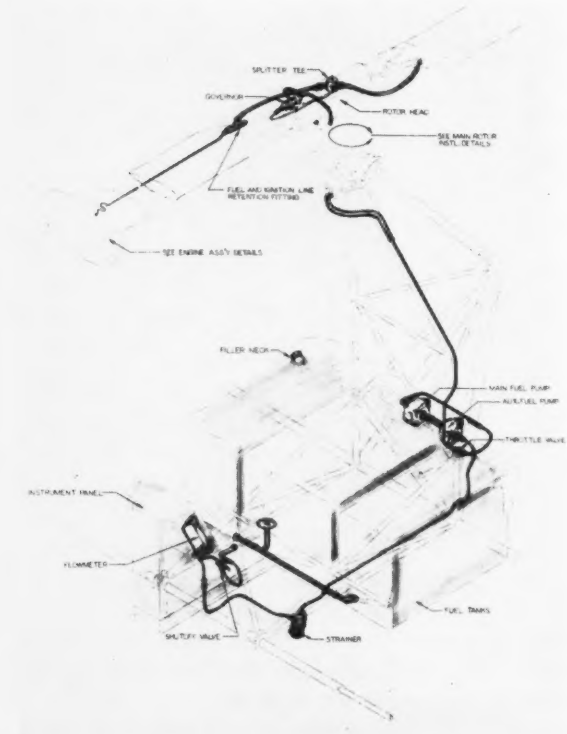

FIG. 7. Fuel system installation.

Mechanical Drives

As indicated in Fig. 6, the transmission normally found in an internally powered helicopter is here replaced by a system of belts and angle drives, the gear box used actually being that which drives the cooling fan of the Hiller H-23B, HTE-2 helicopter. Since there is essentially no rotor torque to overcome, the normal power required for the tail rotor is small, and the total auxiliary power driving the magneto, fuel pumps (dual), and tail rotor is but a small portion of the total power. The starter drive unit, which uses the same transmission system for rotor starting, is actually the designing criterion for the entire system. A hand starter is provided with the ship, as well as an auxiliary power starter drive system. The time required to accelerate the rotors to normal r.p.m. is approximately 5 min.

Fuel System

One of the places where this type helicopter differs from the conventional ship is in the design of the fuel system. This system, as shown in Fig. 7, is relatively simple and conventional until the rotor itself is reached. Here, the first problem is the transmission of the fuel through a rotary seal at the rotor. Then, since a single fuel system is used for both engines, a "splitter tee" is installed at the rotor head to ensure adequate separation of the flow to each engine. In addition, a centrifugal governor is installed to assist the pilot in maintaining constant r.p.m. during flight.

Another item that is built into any tip-mounted system is the rotor pumping action. This action maintains a pressure at the engine which varies with rotor r.p.m. and may be as high as 2,500 lbs. per sq.in. even though only 25–40 lbs. per sq.in. pressure is developed by the rotor-driven pump. This pumping action results in a continuous vacuum at the inboard end of the rotor blade. Difficulty due to lag and overshoot of the governor is encountered during rapid changes in power requirements because of the high pressures and the storage capacity of the blade fuel lines.

Tail Boom and Canopy

For the Model HJ-1, YH-32 the canopy and tail-boom coverings are extensively Plexiglas and Fiberglas. The Plexiglas windshield and Fiberglas canopy are nonstructural installations used for cabin enclosure and fairing purposes. The Fiberglas tail boom is a built-up structural part. As shown in Fig. 8, this boom is built up almost entirely of Fiberglas details, all made in Hiller shops. This part has given the most trouble in the manufacturing program to date because of the newness of the technique.

Various test parts and samples have been built up, several different impregnation methods and materials have been investigated, and different "lay-up" techniques have been tried. At the present time the method of manufacturing detail parts and of assembling them into a complete tail boom appears to be established and to be satisfactory.

Tail Rotor

This Fiberglas tail boom has replaced the welded aluminum tube structure that was used on the original test ships. Another change in the same area has been the replacement of the original rudder with a more conventional tail rotor. The rudder, used on all three of the original ships, was found to be adequate under nearly all flight conditions except for landings with reduced rotor r.p.m. and for hovering flight in relatively large cross winds.

The tail rotor, now installed, easily fulfills the requirements for ease of control, satisfactory rate of turn, and good flight characteristics in hovering flight. As shown in Fig. 9, the tail rotor is built up as a belt-driven, single-bladed, counterweighted rotor. This design was adopted to permit control simplification and some weight-saving. Initial concern about adverse vibratory characteristics has not been proved out on the test installation.

Skid Gear

Another change made from the first XHJ-1 ships flown was the conversion from the tricycle gear to a skid-type landing gear. It is felt that this will improve the ability of the craft to land in rough terrain. In addition, the transfer of the power plant from the body of the ship up into the rotor system tends to move the center of gravity upward so the skid gear imparts a greater landing stability than would be available with the wheel-type gear.

A major departure, so far unsuccessful, was attempted in the design of the cross tubes for the skid gear. An attempt was made to build up glass tubes out of Fiberglas laminate. Design studies actually show considerable weight-saving can be realized with this type of construction. Tubes manufactured by Hiller and by several outside vendors have so far shown promise, but none has been completely successful. Results of static and drop tests have indicated that the major problem with all tubes to date has been a variation in physical properties and in the quality of the bond which could not be adequately controlled.

For the present, steel cross tubes have been tested and released for installation on the first ships. However, tests of the Fiberglas tubes are being continued with every sign that ultimate success is possible.

Other portions of the helicopter, the basic frame, fuel tanks, furnishings, etc., are quite conventional and require no description. Manufacture and assembly of this evaluation model is expected to prove to be an extremely simple process once the tooling and processing

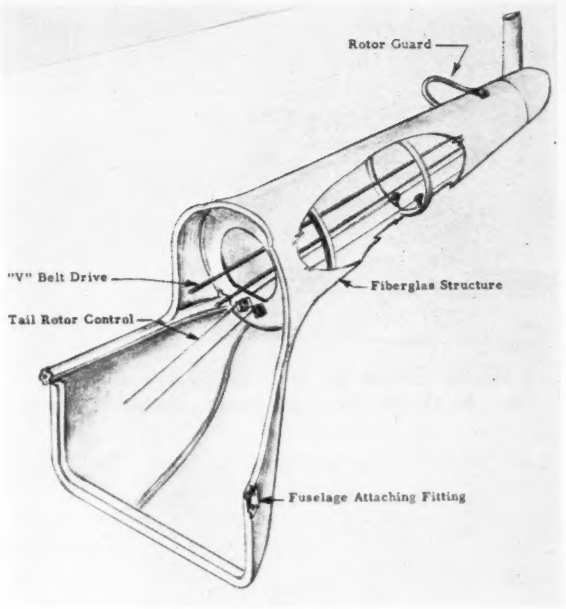

FIG. 8. Tail-boom assembly.

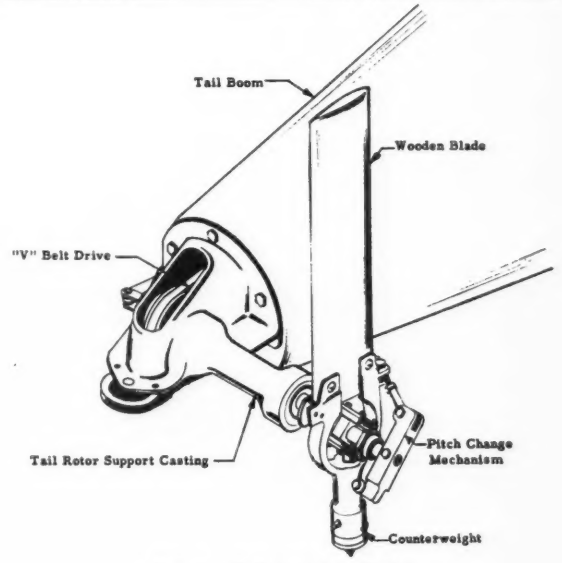

FIG. 9. Tail rotor installation.

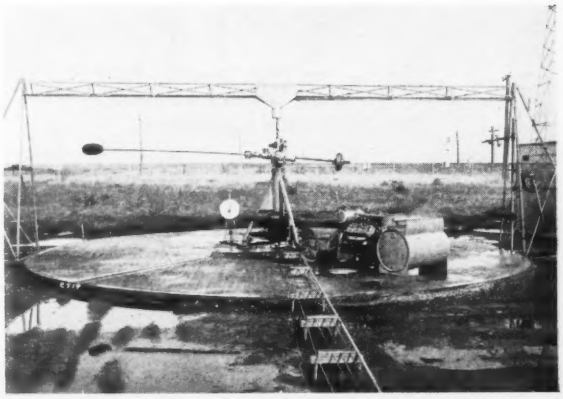

FIG. 10. Ram-jet engine whirl stand facility.

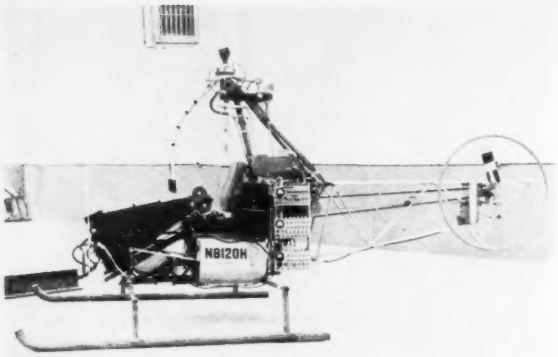

FIG. 11. Flight-vibratory helicopter—instrumentation.

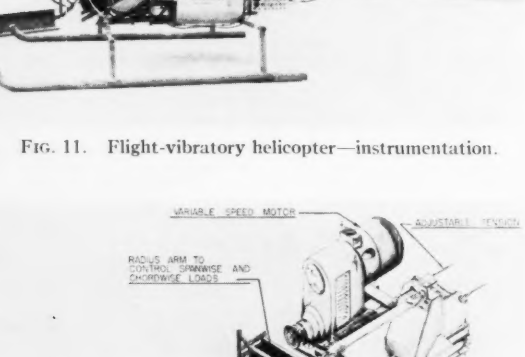

FIG. 12. Main rotor-blade fatigue test jig.

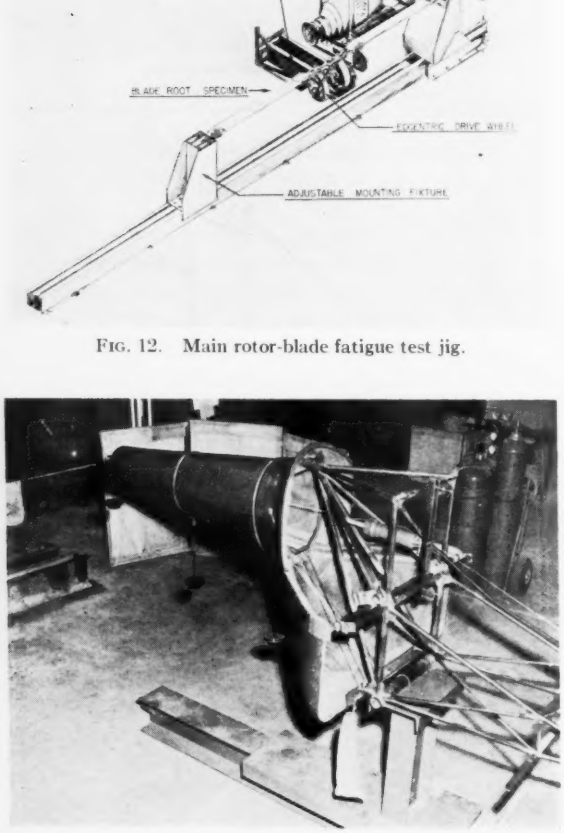

FIG. 13. Static test of tail boom.

is established. Early hopes of design and manufacturing simplification, due to the nature of the design, seem to be borne out by the rapidity with which assemblies are being made in the Hiller shop.

TEST PROGRAM

Although many hours of test work on the early test ships, and particularly on the engines, were done prior to the start of this program, a whole new field of testing was entered with the advent of the HJ-1, YH-32 model helicopter.

As an initial item, this turned out to be the first helicopter with rotor tip propulsion to be brought before the Civil Aeronautics Administration for certification and, as such, posed many unfamiliar problems.

Engine Testing

The first question was whether the engines should be certificated separately and then as an installation, which is conventional, or whether they should be certificated directly on the ship since the method and nature of the installation has so much greater an effect on the tip-mounted engine than it does on a more conventionally mounted engine. It was decided, however, that the engines would be certificated separately, as usual, so Hiller Helicopters is now faced with the dual problem of certificating a helicopter and, simultaneously, an engine.

The engine tests, now underway, occur in two parts. The first part consists of structural substantiation and is conducted on the engine whirl stand, shown in Fig. 10, with the engine being driven through a repeated series of conditions designed to substantiate the engine structure for a given number of hours. The second portion of the testing consists of establishing the operational characteristics of the engines, and this work will be done on the ship during actual flight tests.

One final item of interest in the engine certification program is the problem of establishing an engine power curve for each engine series which may be used for calculations of helicopter performance. The question here arises of how to take static test stand data and correct for all of the effects of contamination, drag loss, etc., which differ from the operating whirling condition, so that this data may be used for the establishment of a helicopter "in-flight" power curve. A method of doing this and of correlating these data with flight-test information has been developed by Hiller and will be used to accomplish this work on the present ship.

Flight-Vibratory Testing

Another item of extreme importance in the test program is the "flight-vibratory" test. This test is made only to determine the loading characteristics of the rotor system. In the case of the HJ-1, YH-32 certification, this test has been expedited slightly by converting one of the original XHJ-1 ships into a flight-vibratory model. The major change made here was the installation of an HJ-1 rotor system on the XHJ-1 ship and the conversion of some other minor items such as replacing the tiller control with conventional foot pedals and the installation of the tail rotor.

This ship is now being instrumented for flight testing. As can be seen in Fig. 11, the instrumentation has developed into a major project. In addition to the oscilloscope, accelerometer, and other instruments normally carried for these flights, there is also a complete photo

panel installed to replace an observer. This photo panel will record the readings of 14 different instruments simultaneously, thus reducing the work of the flight observer to a minimum.

The installation of strain gages on the test blades for this ship has been something of a problem. As mentioned before, the blades are built by Hiller and have not been previously tested. Since they are of all-metal construction, this means that strain readings must be taken every few inches along the blade to determine accurately the stresses existing along the blade. This installation has resulted in the creation of a fairly "dirty" airfoil with which the ship must be flown. To date, however, good luck has been had with the flight testing of the ship, and only a few strain gages have been deleted for unsatisfactory service since the testing of the ship was started.

Blade Fatigue Testing

Following the completion of all flight-vibratory testing, the data will be reduced and the results used to establish proper loadings for the blade fatigue tests. These tests are also a little out of the ordinary since the extremely high centrifugal loads developed by the engine installation at the blade tip require a fairly elaborate setup to duplicate. The blade fatigue jig used to test two blade root sections at one time is shown in Fig. 12.

Tail-Boom Tests

The tail-boom installation, being a somewhat unknown structural quantity, was static-tested to determine its structural limitations. The test setup is seen in Fig. 13. All the critical loads on the tail boom were duplicated up to ultimate loads, and then the most critical loading condition was continued to destruction of the boom.

An interesting aspect of this test is that it was performed on a tail boom built up with one less layer of Fiberglas cloth than the drawings called for, and the success of the test permitted a change to be made and some weight-saving to be accomplished.

Other routine testing, such as castings tests, endurance tests, and performance tests, will be run in the near future, but the tests just described cover the major items of interest.

Future Program

Just as the XHJ-1 ships were built to evaluate the engines to be used for tip mounting, so the HJ-1 YH-32 model is now being built to evaluate the whole concept of tip-mounted ram-jet power for helicopters. It is felt that the potential of the Hiller-Hornet design concept is unlimited and that the quickest way of determining the proper procedure to use in order to take advantage of this potential is to build and fly models of that general type. Thus, the Hiller-Hornet is now being built for evaluation both in its own right and as a concept of possible future designs.

The placing of these ships in the hands of the Military for evaluation will quickly prove the claims of lower maintenance and lower cost made for this type of helicopter, just as the manufacturing of these first ships has proved, to us, the claims of simplicity and ease of manufacture.

It is our feeling that the Hiller-Hornet will be a good proving ground for the philosophy of tip-powered helicopters and for the philosophy of ram-jet-powered helicopters, and, to this end, we have done all in our power to make the ship truly representative of its kind. With what we have today and what we expect to have tomorrow, we feel a substantial addition has been made to the art of helicopter design.

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Spreading of Supersonic Jets in Supersonic Streams*

JOHN G. WILDER, Jr.,† and KENNETH HINDERSINN‡

Cornell Aeronautical Laboratory, Inc.

ABSTRACT

The behavior of subsonic and supersonic jet streams exhausting into a supersonic stream has been investigated experimentally in a small supersonic wind tunnel. The rate of spreading of the jet was determined over a wide range of flow conditions, and a correlation of the experimental results with a theoretical analysis is made. The theoretical analysis for the prediction of jet spread includes two empirical constants that were evaluated by means of the experimental data. Having evaluated these constants, it is possible to predict the spread of a supersonic jet exhausting into a supersonic stream with engineering accuracy within the limits of the experimentation reported herein.

The effects of normal and oblique shocks in the tunnel, inclination of the jet stream to the tunnel stream, and wakes in the tunnel stream on behavior of the jet stream were also studied experimentally. The particular condition that promoted the most rapid mixing and, therefore, the most rapid deterioration of the jet stream was that of passage through a strong normal shock which traversed the tunnel supersonic stream. The rapid deterioration of the jet stream under these conditions appeared to be the results of the upstream propagation of pressure signals through the subsonic jet stream and were of the general nature of shock-boundary-layer interaction phenomena. Similar, though lesser, effects occurred in some cases with supersonic jets in the supersonic stream.

INTRODUCTION

WITH THE ADVENT of jet propulsion, the behavior of a jet stream after leaving a nozzle and the influence of the surrounding medium on the jet stream have become of paramount interest to the wind-tunnel designer who must plan tunnels capable of testing operating jet engines. Although a considerable amount of data was available on low-speed jets, particularly for unheated jets exhausting into still air,[3] almost no data were available on heated subsonic and supersonic jets exhausting into a supersonic stream, under conditions at least approximately simulating those which would be encountered in a propulsion wind tunnel. The research program reported herein was aimed at providing some data of use to the designer within this regime that, having been of little practical interest before, had been almost wholly ignored.

Probably the most difficult single problem faced by the designer of a modern propulsion wind tunnel is that of the removal of almost all of the products of combustion of an operating jet engine from a closed-return supersonic tunnel without lowering the tunnel diffuser efficiency appreciably and without causing undue aerodynamic effects on the model being tested, while at the same time restricting the pumping power required for the scavenging system within tolerable limits. It is apparent that the above briefly outlined design criteria demand a precise knowledge of the jet-stream behavior after it leaves the nozzle, and, since wind-tunnel contamination by exhaust products is of primary concern in any propulsion wind tunnel, the transfer of mass from the jet stream to the tunnel stream was actually the prime measurement required. This measurement is a difficult and laborious one to make by direct sampling techniques, and so it was desirable to determine whether any of the usual aerodynamic measurements of static pressure, total pressure, and total temperature could be used to obtain equivalent information. Low-speed theory and experiments suggested that the transfer of total temperature (energy) would be similar to that of mass but that both would differ from the transfer of momentum (as shown by the jet velocity profile). Early exploratory experimentation revealed that, while total temperatures and pressures could be measured in the streams and in the mixing region with an acceptable degree of accuracy and reproducibility, static pressure measurements were on the whole unreliable, due to the presence of shock waves and such discontinuities throughout the supersonic flow field. This, naturally, precluded the possibility of measuring velocity profiles with any confidence. It was then desirable to compare jet-spread data as determined from stagnation temperature surveys with those resulting from direct sampling. The sampling data were obtained using a special model setup in which 100 per cent of the jet stream was CO_2 and the tunnel stream was air. Samples were extracted at various traverse points at each of five longitudinal stations downstream of the jet-nozzle exit. These samples were then analyzed for per cent CO_2 content in order to determine the degree of mixing. Comparison of these data with those determined from total temperature measurements is made in Fig. 1. In this figure, the points noted as being from a T analysis were computed in the following manner.

Define β_m as the per cent of jet mass present in any given sample, or,

$$\beta_m = m_1/(m_1 + m_2)$$

where

m_1 = mass flow from the jet nozzle
m_2 = mass flow from the tunnel stream

Then, on the assumption that energy and mass transfer are similar,

$$(m_1 + m_2)T = m_1T_1 + m_2T_2$$

Presented at the Propulsion Session, Annual Summer Meeting, IAS, Los Angeles, July 15–17, 1953.

* This work was performed under Air Force Contract No. W33-038 ac-21809 relating to the investigation of air exchange problems in supersonic wind tunnels.

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so that

$$\beta_m = (T - T_2)/(T_1 - T_2) = \beta_T$$

The Mach Numbers (and velocities) of the respective streams compared in Fig. 1 were not the same, being $M_1 = 2$ and $M_2 = 1.78$ for the sampling analysis and $M_1 = 1.98$ and $M_2 = 1.4$ for the temperature or heat-transfer analysis. In both cases, however, the primary nozzle pressure was adjusted for full expansion. All experimental data gathered in this research indicate that this difference in the initial Mach Numbers would have little effect on the rate of jet spread for the regions having constant velocity cores considered here. A study of the figure indicates that the mass distribution is measured by the two methods within about 5 per cent of each other. This difference is within the experimental accuracy of the sampling technique employed.

It should be mentioned that the inherent errors involved in the temperature-measuring technique (i.e., heat transfer through the uninsulated jet-nozzle walls to the boundary layer on the outer sides generated by the tunnel stream) should make the data conservative, inasmuch as it would result in the production of a wider spread than actual mass transfer would give.

Notation

p, p_3	= stagnation or total temperature
T, T_3	= stagnation or total temperature
p	= pressure (static)
ρ	= density
u	= velocity
M	= Mach Number
m	= mass flow
x, y	= coordinates
r_T	= radius of jet stream for $\beta_T = 0.5$
a	= distance from jet-nozzle exit to fictitious source
L	= a characteristic length
β_m	= $m_1/(m_1 + m_2)$
β_T	= $(T - T_2)/(T_1 - T_2)$
ϵ	= experimental coefficient
ξ	= a function defined as = $\int \epsilon \, dx$
α	= shock angle
θ	= jet-spread angle
γ	= ratio of specific heats
K, b, c	= constants

Subscripts

0	= undisturbed secondary stream
1	= primary or jet stream
2	= secondary or tunnel stream
X	= conditions upstream of shock
Y	= conditions downstream of shock
A	= average

Description of Experimental Apparatus

Cornell Aeronautical Laboratory's suction-type two-dimensional supersonic wind tunnel was used to generate the "secondary" or tunnel stream. The open intake of the tunnel facilitated the insertion of a small two-dimensional nozzle to generate the jet (primary) stream (Fig. 2). The general arrangement of the major components of the experimental apparatus is shown in Fig. 2. The primary or jet nozzle was cantilevered such that the portion of the nozzle in the sonic and supersonic regions was free of any supporting structure, thereby eliminating any shock waves or discontinuities resulting from the primary nozzle other than those originating at the nozzle exit. Air under ordinary room conditions was employed as the medium of the secondary stream. The primary stream was air obtained from the Laboratory high-pressure line and heated.

Five tunnel blocks of two-dimensional design were used to provide the supersonic secondary streams. These tunnel blocks produced Mach Numbers of approximately 1.2, 1.4, 1.7, 1.8, and 2.0. The $M = 2.0$ block was used only in the normal shock studies. The test section area of these nozzle blocks ranged from

CONCENTRATION OF THE PRIMARY STREAM USING SAMPLING DATA AND TOTAL TEMPERATURE MEASUREMENTS

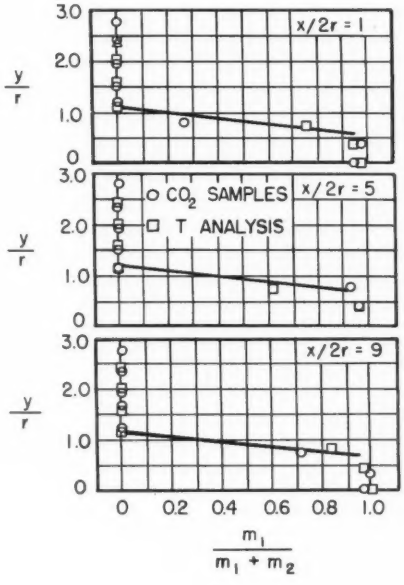
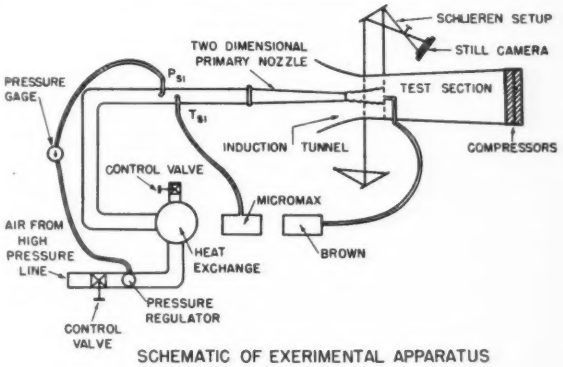


Fig. 1



SCHEMATIC OF EXERIMENTAL APPARATUS

Fig. 2

about 9 sq.in. to about $12^1/_4$ sq.in. All sections had provisions for the installation of $6^1/_2$-in. diameter glass discs in the side walls for observation and schlieren studies and for the insertion of survey probes through the top wall.

Four small two-dimensional nozzles were used to generate the primary or jet stream. These nozzles had identical exit dimensions of 0.348 in. by 1.00 in., and the throat areas were varied to produce Mach Numbers of 1.0, 1.4, 1.8, and 2.6. Subsonic primary Mach Numbers were obtained with the $M = 1.0$ nozzle by throttling the primary stream pressure below the critical. For the oblique shock studies, a wedge with a 15° included angle was mounted on spacers (to clear the boundary layer) on the bottom of the test section. The design shock angle for the particular tunnel Mach Number was 50°, and an angle of 52° was actually measured. Two sets of wake-producing blocks were used with the $M = 1$ and the $M = 2.6$ primary or jet nozzles to study the effect of wakes on rate of mixing and jet spread. Each set contained two blocks, one with a base dimension of 0.54 times the jet-nozzle depth and the other with a base dimension of 1.08 times the jet-nozzle depth. In the experiments, these blocks were attached to the outer wall of the jet nozzle with the base in the plane of the nozzle exit on one wall only (i.e., an asymmetrical configuration was employed). Two sets of curved extensions for the $M = 1.0$ and $M = 2.6$ jet nozzles were used to produce jet streams inclined with respect to the tunnel stream. Each set contained two extensions: one producing a jet stream inclined at a 10° angle with respect to the tunnel stream and the other producing a jet stream inclined at a 15° angle.

The working medium for the jet stream (except for the sampling tests using CO_2) was air from the Laboratory compressed-air line which was heated by means of a 50-kw. resistance-type electric heater. Regulation of the jet-stream total pressure was achieved by the use of a Climax Engineering Company pressure regulator when the total pressure was greater than atmospheric. For primary stream total pressure less than atmospheric, the jet-nozzle supply line was opened to the room upstream of the electric heater. It was then possible to set any pressure less than atmospheric by means of a simple throttling valve. Temperature regulation was achieved by using a Leeds and Northrup Company temperature regulator to control one of the three resistances in the 50-kw. heater, the two remaining resistances being controlled manually for gross changes in airflow rate through the heater. Using the system described above, it was possible to maintain the stagnation temperature to within ±2°F.

To supply the CO_2 for the sampling tests, a bottle farm feeding a manifold was employed so that commercially available CO_2 bottles might be used. In these tests, no heating of the CO_2 was attempted. The "bottle farm" method was satisfactory and inexpensive for tests of short duration but would become extremely expensive for any systematic broad experimentation, such as that done with heated air.

Pressure and temperature surveys were made with conventional single-tube probes utilizing a double-wedge section support or shank such that waves induced by the probe support would be attached to the shank at practically all stream Mach Numbers, except the very low supersonic values. It was necessary to use the single-tube probes as no rake could be conveniently made small enough to avoid choking the small tunnel. A standard-height gage clamped to the top of the tunnel positioned the probe within the stream accurately to within 0.001 in. A Brown temperature indicator was used for the temperature surveys, while standard mercury manometers and pressure gages were used for the pressure surveys. The remaining apparatus consisted of a conventional schlieren rig with a still camera.

Analysis of Turbulent Mixing Data

Pai developed a theory[1] for the prediction of the two-dimensional jet mixing of compressible fluids. The theory was derived basically for the case of laminar motion, and it was suggested that, for turbulent flow, the molecular coefficients of viscosity and heat conductivity be replaced by empirical coefficients of eddy viscosity and conductivity. The basis of this suggestion was, of course, that some degree of success in analyzing low-speed jet mixing had been attained in this manner.[2,3]

Pai's work centered on the jet velocity profile. As explained in the Introduction, it was found experimentally that the most feasible measurement of jet spread was in terms of total temperature. It is, therefore, necessary to transform Pai's equation for jet mixing somewhat if a correlation between experiment and theory is to be found. In Appendix A of reference 4, an equation for predicting jet spread of the same form as Pai's but in terms of stagnation temperatures is developed and appears in final form as

$$\partial T/\partial x = (\epsilon/u_0)(\partial^2 T/\partial y^2) \tag{1}$$

The boundary conditions are:

$$\left.\begin{aligned} u_2 \equiv u_0 &= \text{secondary stream velocity} \\ T_2 &= \text{secondary stream total temperature} \\ u_1 &= \text{primary stream velocity} \\ T_1 &= \text{primary stream total temperature} \end{aligned}\right.$$

$$\left.\begin{aligned} T &= T_1,\ -1 < y < 1 \\ T &= T_2,\ 1 < y,\ y < -1 \end{aligned}\right\} x = 0 \tag{2}$$

Eq. (1) with the boundary conditions of Eq. (2) is similar to the diffusion equation or the equation of heat flow in solids, except ϵ is a function of x. A change of variables puts the equation in a form for which a solution is known.

Let $\xi = \int \epsilon\, dx$, and Eq. (1) becomes

$$\partial T/\partial \xi = (1/u_0)(\partial^2 T/\partial y^2) \tag{3}$$

The boundary conditions of Eq. (3) are the same as those of Eq. (1). The solution of Eq. (3) with the boundary conditions of Eq. (2) is

$$2\beta_T = \phi\left(\frac{1-y}{\sqrt{4\xi/u_2}}\right) + \phi\left(\frac{1+y}{\sqrt{4\xi/u_2}}\right) \qquad (4)$$

where

$$\beta_T = (T - T_2/T_1 - T_2)$$

and

$$\phi(\tau) = \frac{2}{\sqrt{\pi}}\int_0^{\tau} e^{-z^2}dz \qquad \text{(Gauss' error integral)}$$

When $1/\sqrt{4\xi/u_2} \geq 2.5$, one of the error integrals is approximately equal to 1.0 for any value of y, and, at $y = 0$, both error integrals are approximately equal to 1.0 (e.g., $\beta = 1.0$ for the core region). This is the mathematical representation of the fact that in this case, the two sides of the jet behave like independent interfaces. Thus, for the analysis of the core region, Eq. (4) may be simplified to:

$$2\beta_T = \phi\left(\frac{1-|y|}{\sqrt{4\xi/u_2}}\right) + 1 \qquad (5)$$

The boundary conditions employed in the mixing analysis are based on the assumption that the jet exhaust is parallel to the nozzle exit and extends downstream undisturbed by external forces. In reality, this condition is rarely satisfied. The jet boundary may be subject to displacement by one of several factors (e.g., pressure differences between the primary and secondary streams, nonparallel flow at the nozzle exit, and interaction of shock waves and the jet).

To correct this, the assumption is made, subject to experimental verification discussed later in the paper, that the mixing process can be simply considered superimposed on whatever displacements of the jet boundary occur because of gasdynamic effects or other causes. In Eq. (4), according to the boundary conditions of Eq. (2), $y = 1$ corresponds to the undisplaced jet boundary; in other words, the value of y is nondimensionalized with respect to the jet half-width. If the mixing region has a central core and, even in other cases, if the location is not too far downstream, the point $y = 1$, according to Eq. (4), corresponds to the point at which the temperature is one-half way between the values inside and outside the jet, since $\phi(0) = 0$. Then, if this temperature midpoint whose distance from the centerline of the jet is denoted by r_T is determined from the experimental data and the y in Eq. (4) and equations derived from it are referred to this point, due account will be taken of jet boundary displacements according to the assumption of independence of the mixing process of these other effects, and one may write

$$\left.\begin{aligned} 2\beta_T &= \phi\left[\frac{1-(y/r_T)}{\sqrt{4\xi/u_2}}\right] + \phi\left[\frac{1+(y/r_T)}{\sqrt{4\xi/u_2}}\right] \\ &\text{and for the core region} \\ 2\beta_T &= \phi\left(\frac{1-\left|\frac{y}{r_T}\right|}{\sqrt{4\xi/u_2}}\right) + 1 \end{aligned}\right\} \qquad (6)$$

As explained in the Introduction, experimental data indicate mass transfer is similar to energy (temperature) transfer or $\beta_m = \beta_T$, and one may predict the mass transfer with the above equation provided the empirical constants are first determined from experiment.

Assuming similarity of the turbulence mechanism throughout the fluid, Prandtl suggested the relationship for the momentum transport parameter[2]

$$\epsilon = K(U_{max.} - U_{min.})b \qquad (7)$$

where K is a constant, $U_{max.}$ and $U_{min.}$ are, respectively, the maximum and minimum velocities at any streamwise station, and b is the width of the mixing region. On dimensional grounds, for a two-dimensional free jet, the width b should increase linearly with x or $b = cx$ where c is a constant. For the present case, it would appear that ϵ might depend on $t_{max.}$ and $t_{min.}$, as well as $u_{max.}$ and $u_{min.}$, so a relationship of the type

$$\epsilon = K \cdot f(U_{max.}, U_{min.}, t_{max.}, t_{min.})b \qquad (8)$$

is suggested, where f is some function to be determined empirically. For most of the cases studied experimentally, particularly those where a central core of unmixed flow was present, $U_{max.}$, $U_{min.}$, $t_{max.}$, and $t_{min.}$ were constant and $\epsilon = \text{constant} \cdot b$. Using $b = \text{constant} \cdot x$ on dimensional grounds, the formula for ϵ becomes $\epsilon = \text{constant} \cdot x$ or nondimensionalizing x

$$\epsilon = \epsilon_0(x/L) \qquad (9)$$

where L is some characteristic length and ϵ_0 is constant for a given set of boundary conditions. For the cases considered here (within the potential core region), L is not related to the depth of the nozzle, since the existence of the central core indicated that the mixing on each side of the jet took place independently. As mentioned previously, the behavior was like that of two independent interfaces on the two boundaries of the jet. With a linear variation of ϵ, ξ, according to the assumed relation $\xi = \int \epsilon\, dx$, becomes

$$\xi = \epsilon_0(x^2/2L) \qquad (10)$$

Substituting this into Eq. (6) and recalling that the lengths have been nondimensionalized with respect to r_T,

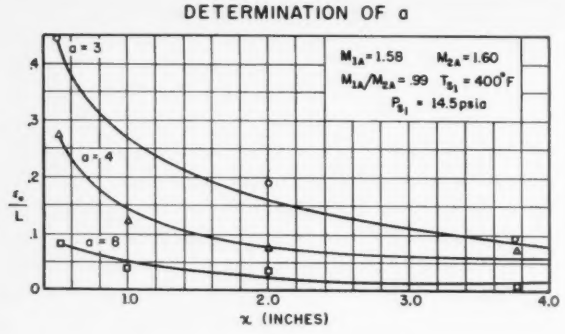


Fig. 3

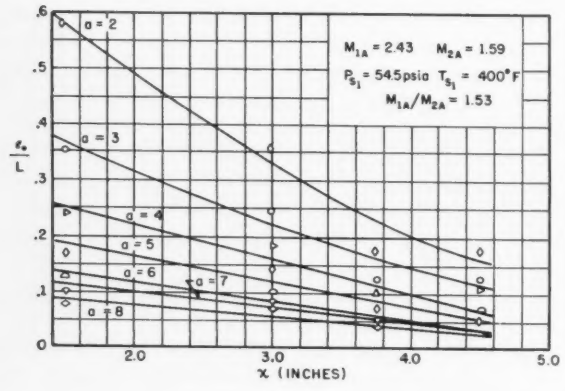


Fig. 4

$$2\beta_T = \phi\left[\frac{1-(y/r_T)}{\sqrt{\frac{2}{u_2}\frac{\epsilon_0}{L}\left(\frac{x}{r_T}\right)^2}}\right] + \phi\left[\frac{1+(y/r_T)}{\sqrt{\frac{2}{u_2}\frac{\epsilon_0}{L}\left(\frac{x}{r_T}\right)^2}}\right]$$

or for the core region

$$2\beta_T = \phi\left[\frac{1-(y/r_T)}{\sqrt{\frac{2}{u_2}\frac{\epsilon_0}{L}\left(\frac{x}{r_T}\right)^2}}\right] + 1 \qquad (11)$$

The variation of ϵ_0/L with some convenient parameter must, of course, be determined from experiment. In practice, the value of ϵ_0/L was determined for various initial stream conditions by measuring β_T, u_2, r_T, x, and y experimentally and substituting these values in Eq. (11) leaving ϵ_0/L to be computed.

A study of the physical conditions at the jet exit would lead one to expect a square mass concentration profile at this station, and, accordingly, the above equations specify that, for $x = 0$, $-1 < y/r_T < 1$, $\beta_T = 1$, and, for $x = 0$, $-1 > y/r_T > 1$, $\beta_T = 0$. A direct plot of the mass concentration, β_T, as computed from stagnation temperature measurements at this station does not give such a distribution but indicates that mixing has already occurred upstream of the primary nozzle exit. This is, of course, physically impossible. The primary causes of this maldistribution appear to be as follows: When two streams of different stagnation temperatures are being studied (and this is a necessary condition for the employment of the temperature-measuring technique), heat flows from the higher temperature primary stream through the steel walls of the uninsulated nozzle to the secondary stream. The external boundary layer that forms on the primary nozzle is heated to a higher total temperature than the secondary stream reservoir temperature. The total temperature survey at the nozzle exit then indicates mixing has occurred upstream of the primary nozzle exit. A second effect is that the stagnation temperature probe being of finite size measures a weighed average temperature between adjacent stream filaments. This precludes the measuring of a sharp temperature gradient as would theoretically exist at the nozzle exit.

At low speeds, the concept of a virtual source some distance upstream of the actual nozzle lip is often introduced to account for finite nozzle size.[3] Further, the details of the mixing process very close to the nozzle lip cannot be expected to be really similar to those well downstream. The virtual source idea also takes care of this effect. A hypothetical starting point for a mixing at a distance, a, upstream of the nozzle lip was, therefore, also introduced in the present case.

Assuming that the mixing source existing at a point starts at a distance, a, upstream of the primary nozzle lip, Eq. (11) may be written

$$2\beta_T = \phi\left[\frac{1-(y/r_T)}{\sqrt{\frac{2}{u_2}\frac{\epsilon_0}{L}\left(\frac{x+a}{r_T}\right)^2}}\right] + \phi\left[\frac{1+(y/r_T)}{\sqrt{\frac{2}{u_2}\frac{\epsilon_0}{L}\left(\frac{x+a}{r_T}\right)^2}}\right] \qquad (12)$$

and for the core region

$$2\beta_T = \phi\left(\frac{1-\left|\frac{y}{r_T}\right|}{\sqrt{\frac{2}{u_2}\frac{\epsilon_0}{L}\left(\frac{x+a}{r_T}\right)^2}}\right) + 1$$

Eq. (12) now includes two unknowns, ϵ_0/L and a. These must be determined from experiment.

The assumption was made in deriving Eq. (12) that ϵ_0/L should be a constant independent of x for any given set of initial stream conditions. To check this hypothesis with experimental results, plots of ϵ_0/L versus x for various chosen values of a were made in Figs. 3 and 4. The experimental points are those computed from Eq. (12) using measured values of β_T, y, r_T, u_2, and x for the chosen value of a indicated. It is evident from these figures that ϵ_0/L approaches a constant for $a = 8$. These two cases are for Mach Number ratios of 0.99 and 1.53. Identical plots for other Mach Number ratios also indicate a value of $a = 8$ satisfied the requirement that ϵ_0/L should approach a constant. In accordance

with Eq. (8), ϵ_0/L was considered to be a function of the velocities and temperatures of the two streams. Correlations of the values of ϵ_0/L with velocity differences, Mach Number difference, and temperature difference, as well as with various ratios of these quantities, were attempted. Most of these attempts were unsuccessful. It was found, however, that good correlation with the ratio M_1/M_2 could be effected. Cross plotting the series of ϵ_0/L versus x graphs (selecting an average value of ϵ_0/L for $a = 8$ in each case) produced plots of ϵ_0/L versus M_1/M_2 shown in Fig. 5. The scatter of points appears to be remarkably small in this graph, considering the wide range of initial stream conditions represented. This graph provides all the information needed for the use of Eq. (12) in predicting jet spread.

The comparison of this theory with experiment for a range of Mach Number ratios from 0.69 through 2.04 is given in Figs. 6–9. A value of $a = 8$ was used for all of these computations, and the values of ϵ_0/L used were the exact values of the experimental points shown in Fig. 5. Selection of the values of ϵ_0/L from the faired curve of Fig. 5 would change the results little.

These figures reveal that Eq. (12) with the values of ϵ_0/L plotted in Fig. 5 predicts the mass ratio extremely well through a wide range of Mach Number ratios. It might be expected that the poorest performance would be near a Mach Number ratio of 1 (Fig. 7) where the shear forces between the streams would be small and

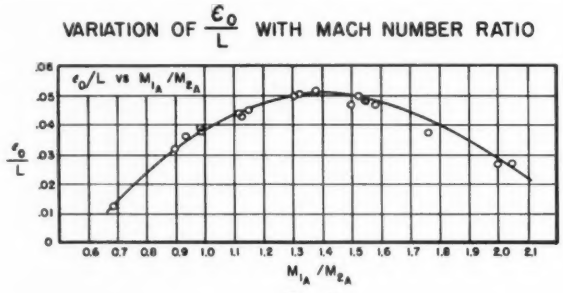


Fig. 5

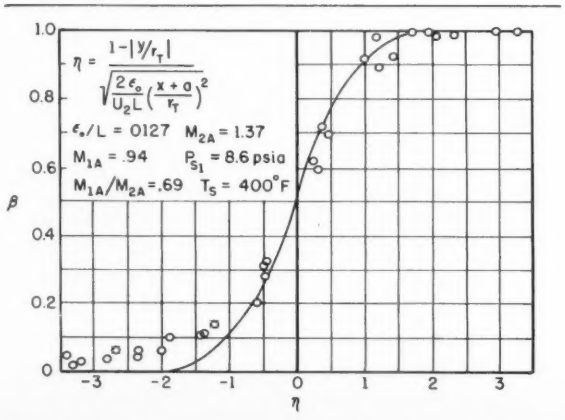

$\eta = \frac{1-|y/r_T|}{\sqrt{\frac{2\epsilon_0}{U_2 L}\left(\frac{x+a}{r_T}\right)^2}}$
ϵ_0/L = 0127 M_{2A} = 1.37
M_{1A} = .94 P_{S_1} = 8.6 psia
M_{1A}/M_{2A} = .69 T_S = 400°F
β
η

FIG. 6. Comparison of experiment with theory. Upper left corner: Ts should be Ts_1.

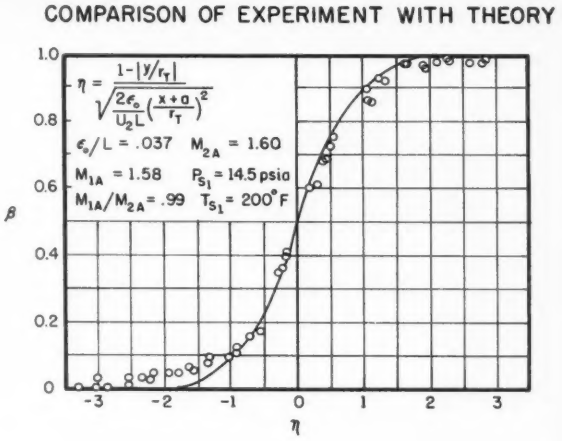

COMPARISON OF EXPERIMENT WITH THEORY
$\eta = \frac{1-|y/r_T|}{\sqrt{\frac{2\epsilon_0}{U_2 L}\left(\frac{x+a}{r_T}\right)^2}}$
ϵ_0/L = .037 M_{2A} = 1.60
M_{1A} = 1.58 P_{S_1} = 14.5 psia
M_{1A}/M_{2A} = .99 T_{S_1} = 200°F
β
η

Fig. 7

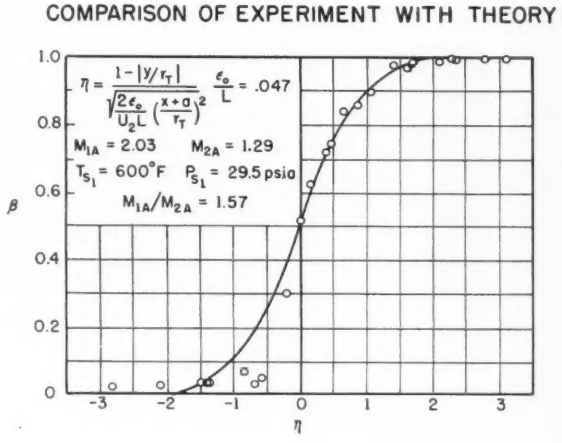

COMPARISON OF EXPERIMENT WITH THEORY
$\eta = \frac{1-|y/r_T|}{\sqrt{\frac{2\epsilon_0}{U_2 L}\left(\frac{x+a}{r_T}\right)^2}}$ $\frac{\epsilon_0}{L}$ = .047
M_{1A} = 2.03 M_{2A} = 1.29
T_{S_1} = 600°F P_{S_1} = 29.5 psia
M_{1A}/M_{2A} = 1.57
β
η

Fig. 8

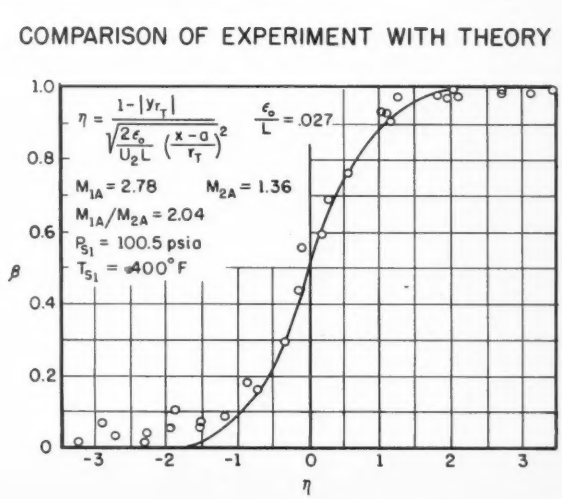


Fig. 9

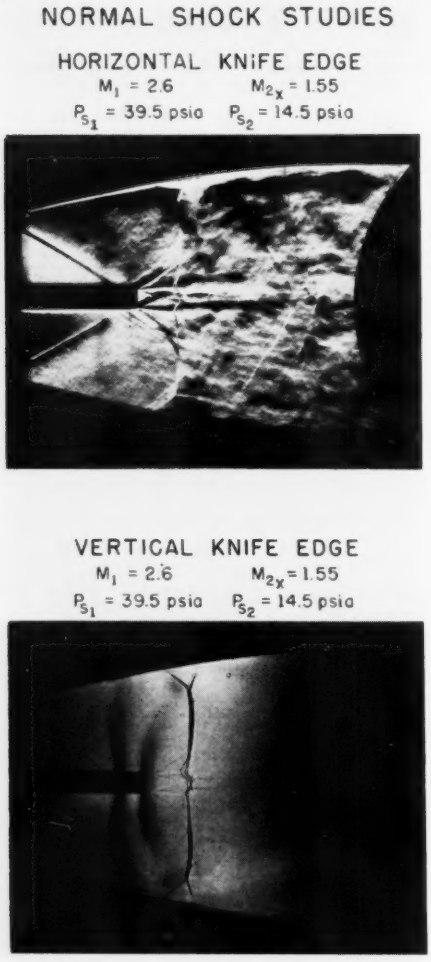


Fig. 10

temperature difference effects might predominate. The graphs, however, indicate good correlation throughout the range investigated.

Normal Shock Studies

Under certain tunnel operating conditions, a normal shock just downstream of, or even in the test section of, a supersonic tunnel may exist. It was recognized that such a shock, if it occurred between a scavenging scoop and the exit of an operating jet engine, might have a profound effect on the jet exhaust spread and thus on the capture problem. Therefore, it was decided to make an attempt to establish the order of magnitude of such effects experimentally during the course of this program. The first attempts to establish a normal shock in the test section, first, by means of a throttling valve in the tunnel diffuser and, later, by means of a second throat, were unsuccessful. It was then decided to use a sharply diverging channel so that shock stability would not be critical. This method was successful and produced the data discussed below.

A representative configuration from the schlieren studies is presented in Fig. 10. In this figure, the flow conditions are identical, the only difference between the photographs being the schlieren knife-edge position. In the picture made with a horizontal knife edge, the turbulent mixing region and interface are emphasized, while in that made with a vertical knife edge, the shock waves are made prominent at the expense of horizontal stria of density gradient.

A study of all schlierens gathered reveals a wave configuration about as one would expect (from a one-dimensional analysis) for the case of a supersonic primary stream of greater Mach Number than the supersonic secondary stream, or $M_1 > M_2 > 1$. Referring to Fig. 13a, where X designates conditions before the shock, Y, conditions after the shock, 1 primary stream conditions, and 2 secondary stream conditions, and assuming one-dimensional flow, one may write, using the well-known shock relations:[5]

$$\frac{p_{2Y}}{p_{2X}} = \frac{2\gamma}{\gamma - 1} M_{2X}^2 - \frac{\gamma - 1}{\gamma + 1};$$

$$\frac{p_{1Y}}{p_{1X}} = \frac{2\gamma}{\gamma - 1} M_{1X}^2 \sin^2 \alpha - \frac{\gamma - 1}{\gamma + 1}$$

and because the static pressures in the two streams before and after the shock must be equal,

$$p_{2Y}/p_{2X} = p_{1Y}/p_{1X}$$

Therefore,

$$\frac{2\gamma}{\gamma - 1} M_{2X}^2 - \frac{\gamma - 1}{\gamma + 1} = \frac{2\gamma}{\gamma - 1} M_{1X}^2 \sin^2 \alpha - \frac{\gamma - 1}{\gamma + 1}$$

or

$$\sin \alpha = M_{2X}/M_{1X}$$

and

$$\alpha = \sin^{-1} M_{2X}/M_{1X}$$

In the limit $\alpha \rightarrow 90°$ as $M_{2X} \rightarrow M_{1X}$.

As long as $M_{1X} > M_{2X}$, $\alpha < 90°$ and an oblique shock should exist in the primary stream. This would result in an apparent contraction of the primary stream, as a stream line is refracted away from the normal upon passing through an oblique wave. Also, as long as M_{1X} remains greater than M_{2X} and the oblique wave pattern exists in the primary stream, the primary stream should theoretically remain supersonic downstream of the shock, whereas the secondary stream would be subsonic after passing through the normal shock. It is apparent from a close inspection of the wave configurations in the photographs that the actual wave patterns realized in practice deviate somewhat from those predicted by a simple one-dimensional analysis such as that above. The photographs (for the cases of two supersonic streams and $M_1 > M_2$) show the normal shock in the secondary and the beginning of the oblique shock in the mixing regions. The oblique shock does not continue to the centerline of the primary stream, however, but

terminates in every case in a small normal shock apparently wholly contained within the undisturbed region of the primary stream—i.e., inside of the turbulent mixing regions. Both the larger normal shock in the secondary, and the smaller normal shock in the primary, show a tendency to interact with the turbulent mixing region in a manner similar to the shock-boundary-layer interaction that produces the lambda shock configuration. It is likely that the situations are similar. The small normal shock in the primary stream cannot be satisfactorily explained by a simple pressure balance concept if a constant Mach Number distribution is assumed through the primary stream. Expansion waves originating at the inside corners of the primary nozzle lip appear to intersect the junction of the oblique waves and the small normal shock in the primary stream. This may influence the wave configuration also.

Again resorting to one-dimensional theory and assuming that the static pressures of the two streams must equal each other before and after a shock, one may show that if $M_{2X} > M_{1X}$ and $M_{1X} \geq 1$ and the shock in the secondary stream is normal, a subsonic compression of the primary stream aft of the shock must occur. The normal shock traversing both streams will not support the same static pressure rise in the two streams of different Mach Numbers. The reverse of the case discussed above might exist—i.e., an oblique shock in the secondary stream and a normal shock in the primary stream would produce the necessary pressure balance, but if a normal shock is induced in the secondary stream, the pressure balance must be achieved by means of some other mechanism. A system that theoretically would balance the pressures consists of a normal shock traversing both streams, followed immediately by an expansion of the cross-sectional area of the primary stream tube on the subsonic side of the normal shock, resulting in compression of the primary stream to the value of the pressure in the secondary stream (see Fig. 13b). This configuration would have a theoretical maximum possible secondary Mach Number for a given primary Mach Number equivalent to the theoretical maximum pressure recovery possible in the primary stream in passing through a normal shock and then being compressed (by means of an infinite area expansion of the stream tube) to the value of its total pressure. In order for this shock configuration to exist, M_2 can only exceed M_1 by a small amount, approximately $\Delta M = 0.25$ maximum difference. If M_2 exceeds this limiting value, the pressure must balance by some other mechanism. Again, the pattern of oblique waves, normal waves, and boundary layer from the outside of the primary nozzle walls interact in a manner somewhat like the lambda shock-boundary-layer configuration. The photographs taken in the study of this configuration show a sudden divergence of the primary channel just downstream of the shocks, indicating the assumed subsonic compression of the primary stream does occur.

An indication of the extent to which the area expansion and mixing of the primary stream are carried is given by total temperature surveys downstream of the normal shock. The results of such a survey at each of two stations downstream of the normal shock for various initial stream conditions are graphed in Figs. 11 and 12.

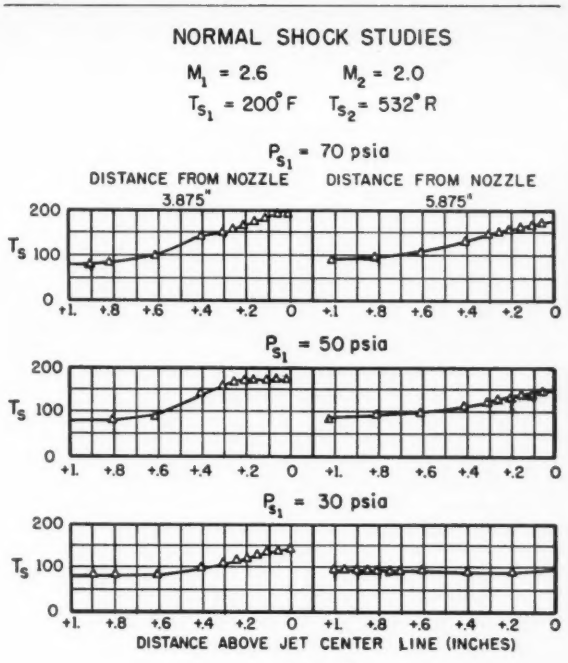

NORMAL SHOCK STUDIES
M1 = 2.6 M2 = 2.0
Ts1 = 200° F Ts2 = 532° R
Ps1 = 70 psia
DISTANCE FROM NOZZLE 3.875"
DISTANCE FROM NOZZLE 5.875"
Ps1 = 50 psia
Ps1 = 30 psia
Ts
200
100
0
+1. +.8 +.6 +.4 +.2 0 +1. +.8 +.6 +.4 +.2 0
DISTANCE ABOVE JET CENTER LINE (INCHES)

Fig. 11

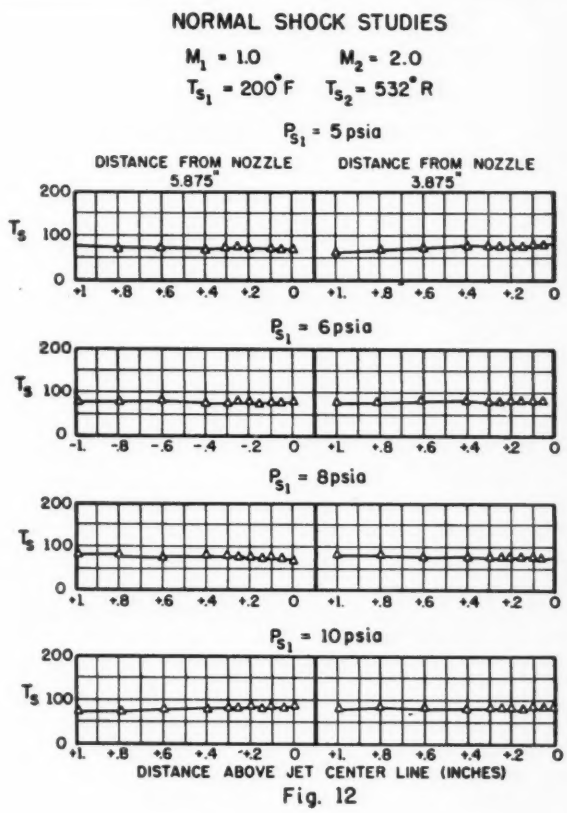

NORMAL SHOCK STUDIES
M1 = 1.0 M2 = 2.0
Ts1 = 200° F Ts2 = 532° R
Ps1 = 5 psia
DISTANCE FROM NOZZLE 5.875"
DISTANCE FROM NOZZLE 3.875"
Ps1 = 6 psia
Ps1 = 8 psia
Ps1 = 10 psia
Ts
200
100
0
+1 +.8 +.6 +.4 +.2 0 +1. +.8 +.6 +.4 +.2 0
-1. -.8 -.6 -.4 -.2 0 +1. +.8 +.6 +.4 +.2 0
DISTANCE ABOVE JET CENTER LINE (INCHES)

Fig. 12

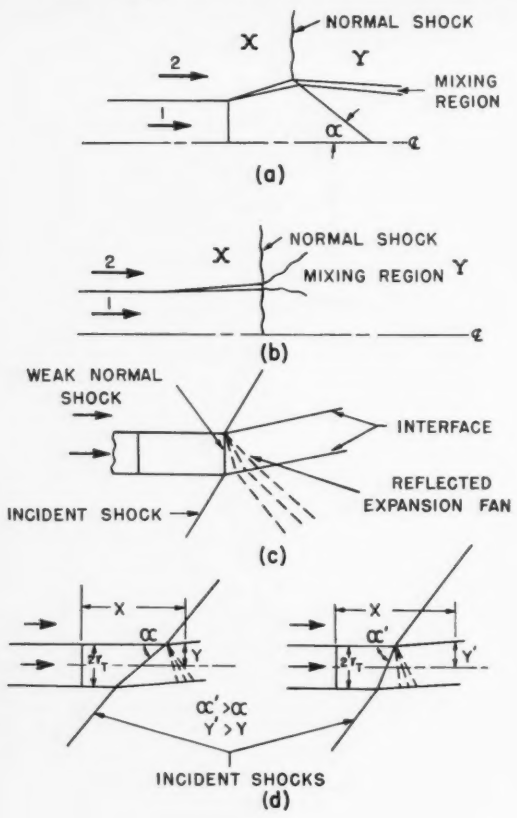


Fig. 13

It is apparent from Fig. 12 that, for the conditions surveyed in this instance, complete mixing has occurred. There is no significant change in total temperature as one progresses across the stream, as was measured in previous cases, when a definite interface between two streams of different reservoir temperatures existed. In Fig. 11, some variation in total temperature is measured for some conditions, but the gradient of the curve is much less than normally measured when no shock is present.

As discussed above, when M_2 exceeds some critical value (approximately $M_1 + 0.25$), the above described wave configuration can no longer balance the pressures between the streams. In the case of both stream Mach Numbers equal to or greater than 1, it appears that the wave pattern is modified somewhat as follows:

The oblique shock originating on the exterior lip of the primary nozzle exit grows larger, blending with the normal shock well out into the secondary stream. A true normal shock no longer appears to exist across the primary stream. In this particular case, a complete absence of strong waves in the primary stream is noted. The secondary Mach Number was the same as that of the previous case, but the primary Mach Number was reduced by the simple expedient of reducing the total pressure of the primary stream. This results in M_2 exceeding the critical value for $M_1 \approx 1.0$. It is rather difficult to guess what the static pressure was at the primary nozzle exit in this case, and measurement was impossible without upsetting the existing wave configuration. If the static pressure is assumed to be that which would exist behind a normal shock in the secondary (where the shock occurs at $M_2 = 1.55$), the total pressure of 8 lbs. per sq.in. absolute in the primary would have been adequate to produce a supersonic primary stream. However, very rapid mixing of the two streams occurred in this case also, as was evidenced by both the photograph and the total temperature surveys (Fig. 12).

The final case to be considered is that of the subsonic primary and supersonic secondary streams. In this case, no waves may exist in the primary stream, and pressure signals may be transmitted upstream within the primary stream. The theoretical limiting M_2 would be that which would produce a static pressure downstream of a normal shock in excess of the primary stream total pressure, in which case flow reversal in the primary nozzle would occur. The shock pattern in each of these cases consists of a combination of oblique waves originating at the primary nozzle exit and a normal shock in the secondary. The effect of the waves on mixing is severe in these cases, producing complete mixing in about ten nozzle diameters downstream (Fig. 12).

With a supersonic primary, the effect is not as severe as with the subsonic primary (Fig. 11); however, the normal shock still promotes mixing at a much more rapid rate than was measured in previous conditions with the normal shock absent.

It is apparent from the above that a normal shock occurring between a scavenging scoop and the exit of an operating jet engine may make the scavenging task difficult and, in the case of a subsonic or near-sonic jet, may require special measures.

Oblique Shock Studies

During normal operation of a supersonic wind tunnel, oblique shock waves can be expected with any change in tunnel stream direction or as a result of reflection of shocks due to models. In the particular case of tunnel operation with a jet engine mounted in the test section, the existence of oblique shock waves becomes most probable. Therefore, it becomes desirable to determine the effect of a strong oblique shock on a jet stream. The necessary oblique wave was generated in the $M = 1.8$ tunnel by the simple expedient of mounting a wedge just outside the tunnel boundary layer on the bottom of the test section. The angle of the resulting shock to the direction of flow was approximately 52°.

Case I

$$M_1 < 1 < M_2$$

In this case, pressure signals may be transmitted upstream, and shock waves cannot exist in the subsonic

primary stream. If a strong oblique shock is induced in the supersonic secondary stream by any means, the primary stream is immediately exposed to a pressure discontinuity along the interface. Since no wave may exist within the primary stream, this pressure discontinuity must be balanced by some other mechanism, such as a sudden enlarging of the primary channel resulting in an equivalent pressure rise within the primary stream. Theoretically, the primary stream being subsonic rather than supersonic should not affect the initial wave angle in the secondary stream so long as sufficient tunnel drive power is available to prevent choking.

Unfortunately, sufficient power was not available in the experimental rig used for these experiments to produce the expected oblique shock in the secondary when the primary stream was subsonic, and the actual shock produced approached a normal tunnel shock with a reacceleration of the flow aft of the shock within the physical throat created by the presence of the wedge (see Fig. 14). It is apparent from the schlieren, however, that an enlarging of the primary stream does occur upstream of the shock.

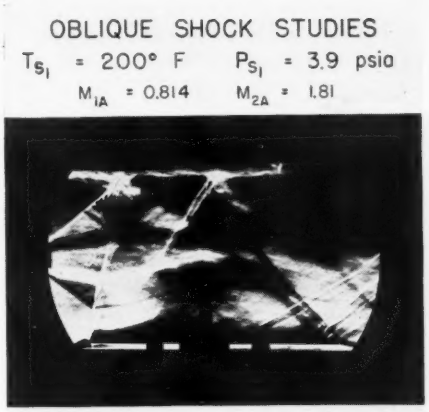


Fig. 14

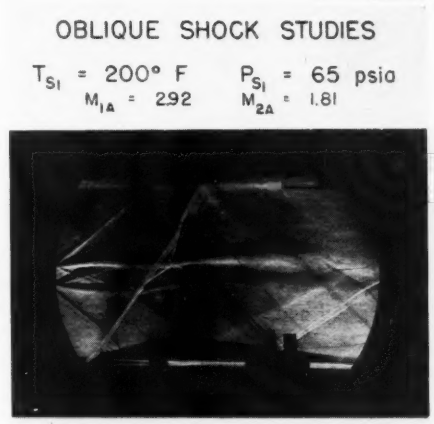


Fig. 15

Case II

$$M_1 \approx 1,\ M_2 > 1$$

For these conditions, one would expect a weak normal shock in the primary stream, regardless of the angle of the oblique wave in the secondary stream. The secondary stream must turn through a given angle (according to plane shock theory) upon traversing the oblique shock, and, thus, if the two streams are to remain essentially parallel aft of the shock configuration, the primary stream must also turn through the same angle. It appears most probable that a wave opposite in sign to the impinging wave would be reflected from the interface into the primary stream to accomplish this turning of the primary stream according to Fig. 13c.

Unfortunately, it was impossible to maintain the boundary conditions due to insufficient power available in the experimental rig; therefore, the above must be considered conjective with no experimental verification. As in Case I, when the primary stream Mach Number was near 1, the tunnel power was insufficient to prevent the degeneration of the oblique shock into a tunnel normal shock.

Case III

$$M_1 > 1 < M_2$$

According to plane shock theory, the angle α of Fig. 13d must be such that the resulting turning of the primary stream would produce parallel flow between the two streams downstream of the shock configuration. This condition would be ensured by a reflection from the interface into the primary stream of a compression wave or an expansion fan, depending on the requirements for parallel flow. As shown diagrammatically in Fig. 13d, a decrease in the Mach Number of the primary stream (all other conditions remaining constant) would be expected to result in an increase in the displacement of the primary stream as a function of x and a decrease in the contraction of the primary stream.

The schlieren photographs (Fig. 15) indicate that the effect of the oblique shock is complicated by the reflection of extraneous shocks originating upstream at the nozzle exit. The effect of these reflections plus the added difficulty in accurately determining the position of the initial intersection of the jet stream and the oblique shock restrict an accurate comparison of the experimental results with the theoretical calculations based on plane shock theory. Nevertheless, a comparison was made by restricting the calculations to a position approximately 1.61 radii downstream of the position of initial intersection of the jet stream and the oblique shock that is upstream of the major portions of reflections from extraneous shocks.

Table 1 lists the theoretical calculations and experimental measurements for the contraction and displacement of the jet stream with three different primary stream Mach Numbers and a primary stream stagnation temperature of 200°F.

Table 1 indicates qualitative agreement between theory and experiment. The one case of $M_{1X} = 2.66$, which is full expansion for the primary or jet nozzle, gives good quantitative agreement. This would give

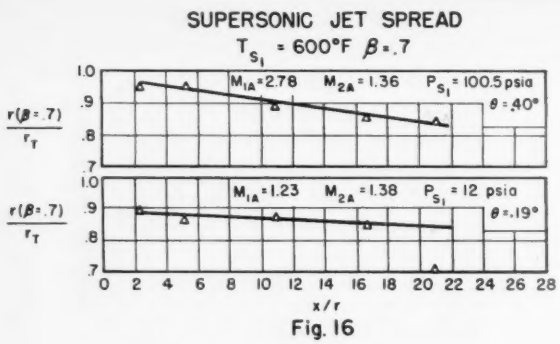


Fig. 16

TABLE 1

M_{1X}	Contraction		Displacement	
	Theory	Experiment	Theory	Experiment
2.30	$0.535r_T$	$0.429r_T$	$0.373r_T$	$0.286r_T$
2.66	$0.415r_T$	$0.415r_T$	$0.226r_T$	$0.211r_T$
2.92	$0.300r_T$	$0.360r_T$	$0.151r_T$	$0.122r_T$

the best agreement as the two streams are most nearly parallel, thereby eliminating an error present in the other two cases.

In summing up, it appears that plane shock theory may be used to predict qualitatively the contraction and displacement of a jet stream in passing through an oblique shock, but, for quantitative agreement, the flow field would have to be free from extraneous disturbances.

Supersonic Jet-Spread Angle

From the previous analysis of the β_T profiles, it was found that, for all practical purposes, the profiles could be considered symmetrical about $\beta_T = 0.5$. In determining the mass concentration from total temperature measurements, it was found that more accurate results could be obtained when the values of $T_1 - T_2$ and $T - T_2$ were the greatest. In view of this, it was decided to investigate the behavior of the jet width at $\beta_T = 0.7$ as a function of the distance downstream of the primary nozzle exit. To ensure accuracy in the measurements, it was decided to use experimental data in which T_1 was equal to 600°F., which gives the largest values of $T_1 - T_2$.

The effect of waves in the jet was normalized by the use of r_T, and the various plots of $r_{(\beta=0.7)}/r_T$ versus x/r are presented in Fig. 16. A preliminary analysis indicated that the jet spread would vary as some function of the ratio of the Mach Numbers of the two streams. Consequently, the flow parameters of the test conditions were chosen accordingly. The value of the jet spread for each set of conditions was determined by measuring the slopes of the various curves in Fig. 16 (plotted to scale).

The values of θ (the angle of jet spread) obtained in this manner are plotted in Fig. 17. It is easily demonstrated from this graph that θ may be closely approximated by the relation

$$\theta = K(M_{1A}/M_{2A})$$

where $K = 0.20$.

The most significant result of this analysis, however, is the fact that the maximum jet-spread angle measured in this study did not exceed 0.40°, which is most desirable where the scavenging problem is being considered. It is also noteworthy that all schlierens substantiate the small angle of jet spread.

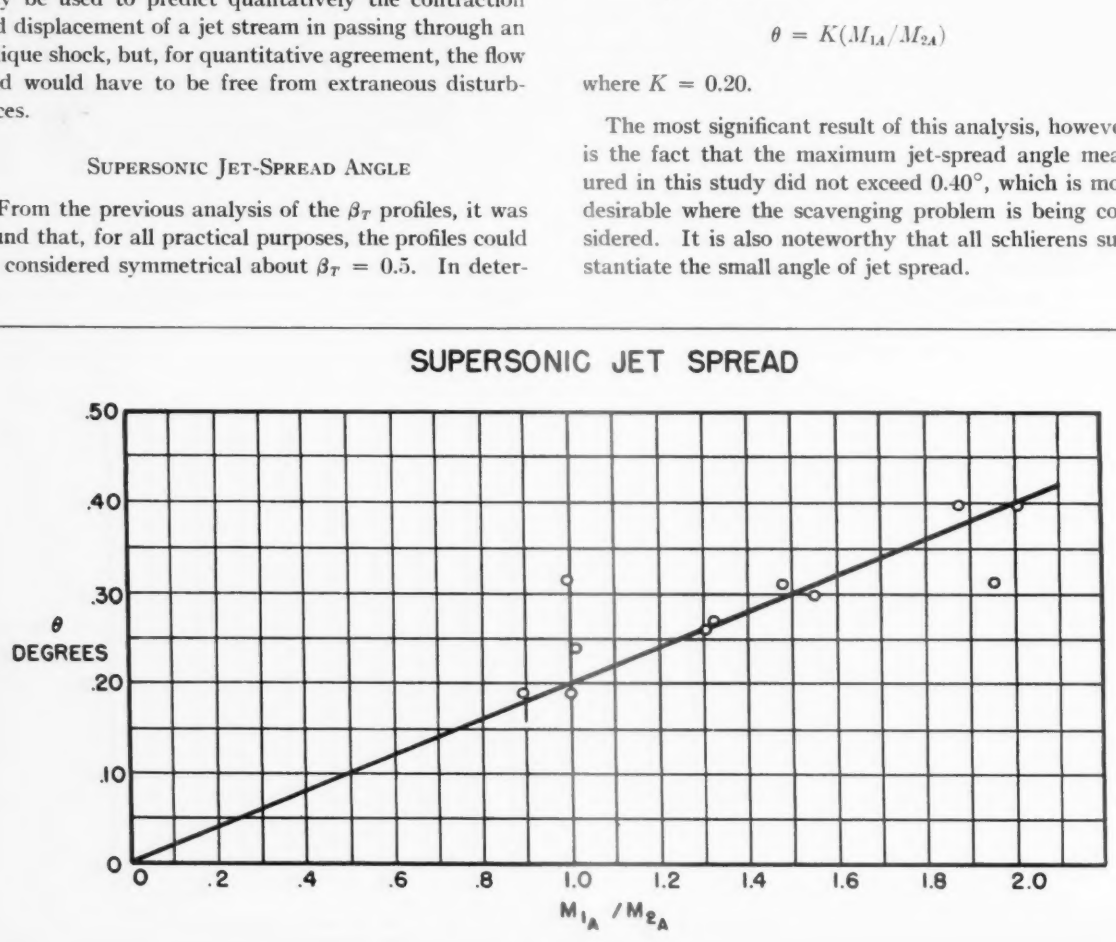


Fig. 17

Analysis of Boundary Displacement

As previously mentioned, the behavior of supersonic jets downstream of the nozzle exit may be resolved into two parts: (1) the initial displacement of the jet boundary (due to over- or underexpansion of the primary stream) and wave reflections produced by these conditions and (2) the turbulent mixing process. A method for predicting the spread due to turbulent mixing has been discussed. This section is concerned with the mechanical effects of over- or underexpansion on boundary displacement.

Defining the parameter r_T as the $^1/_2$ concentration point (i.e., $\beta_T = 0.5$ would be the jet boundary if there were no mixing), the general phenomenon of boundary displacement may be shown graphically with plots of r_T/r versus x/r. This method of presentation merely eliminates the effect of turbulent mixing so that boundary displacement may be studied unimpeded by other effects.

On the basis of the linearized theory of supersonic flow, it can be shown that the reflection of Mach waves from an interface depends on the reflection ratio

$$R = \rho_1 u_1 \sqrt{M_2^2 - 1} / \rho_2 u_2 \sqrt{M_1^2 - 1}.$$

When this ratio is unity, no reflection from the interface occurs, while the magnitude of the reflection increases as the ratio either increases or decreases away from unity. The ratio between $\rho_1 u_1 \sqrt{M_2^2 - 1}$ and $\rho_2 u_2 \sqrt{M_1^2 - 1}$ is thus an indication of the amount of reflection to be expected. The values of the ratio of these two quantities, R, are noted on significant graphs as an indication of the reflections to be expected from a theoretical consideration. The experimental indication of reflected waves from the interface appears as waves in the r_T/r versus x/r plots. As these plots approach a straight line, the reflected waves must become weak or disappear.

A typical example of this phenomenon is presented in Fig. 18. Fig. 18 is a plot of r_T/r versus x/r for R values

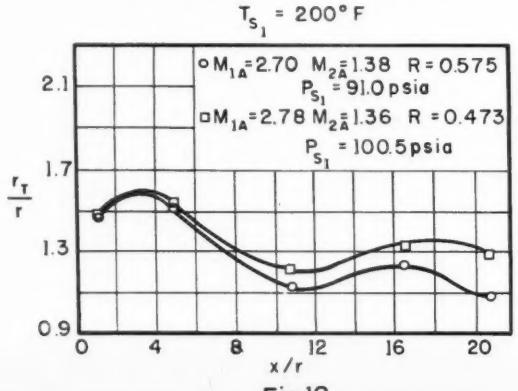


Fig. 18

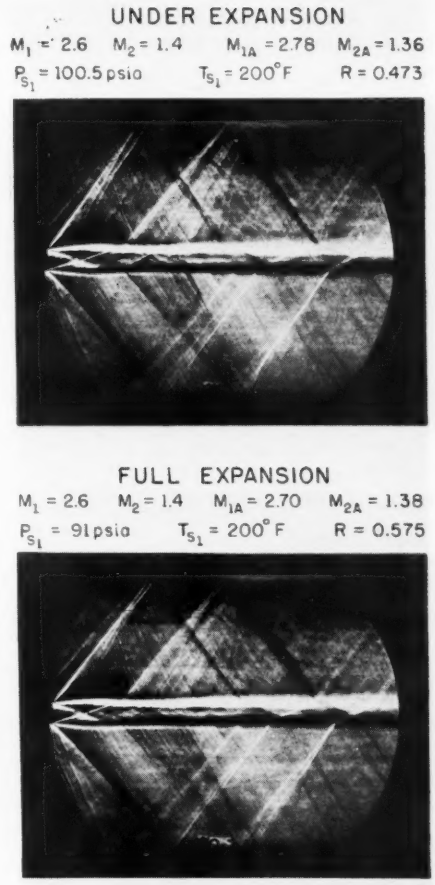

UNDER EXPANSION
M_1 = 2.6 M_2 = 1.4 M_{1A} = 2.78 M_{2A} = 1.36
P_{S_1} = 100.5 psia T_{S_1} = 200° F R = 0.473
FULL EXPANSION
M_1 = 2.6 M_2 = 1.4 M_{1A} = 2.70 M_{2A} = 1.38
P_{S_1} = 91 psia T_{S_1} = 200° F R = 0.575

Fig. 19

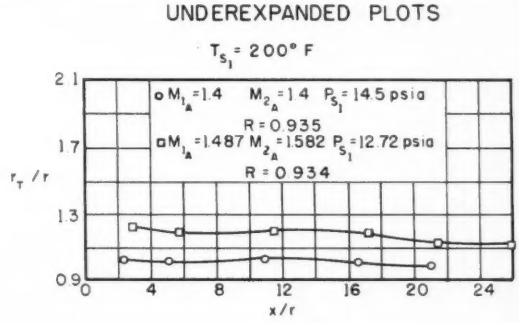


Fig. 20

appreciably different from 1.0. The waviness of the graphs clearly shows the effect of reflected waves. The schlieren photographs corresponding to these graphs are given in Fig. 19. The reflected waves and the initial displacement of the jet boundary due to underexpansion are clearly visible here. To illustrate the results of approaching an R value of 1.0, Figs. 20 and 21 are given. In Fig. 20, it is clear that the r_T/r graph approaches a straight line and the schlieren photograph (Fig. 21) shows only weak reflections from the interface. It

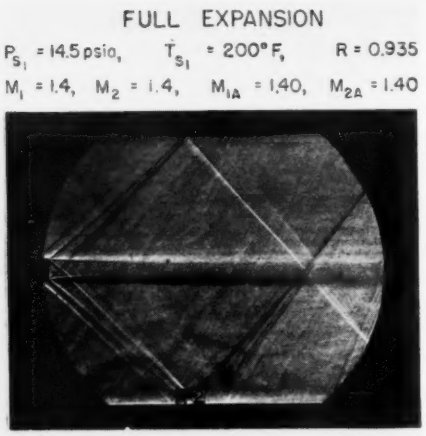


Fig. 21

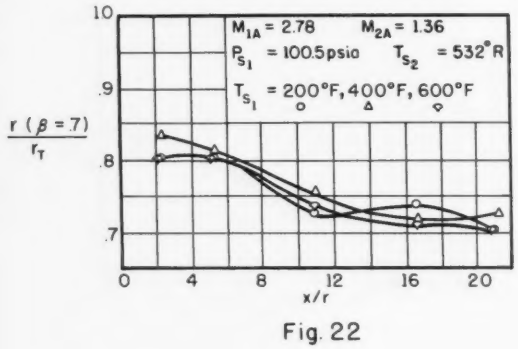


Fig. 22

should be noted that, in the case of Fig. 20, one curve is from a fully expanded jet with the $M = 1.4$ nozzle, while the other is a plot of an underexpanded jet with the $M = 1.0$ nozzle. The value of the reflection ratio for each of these cases as noted was found to be almost unity (i.e., indicating no wave reflection from the interface). The shapes of the curves in these two cases are almost identical, and they approach a straight line. The only noticeable difference is the magnitude of the r_T/r values, which is to be expected because of the difference in the geometry of the two nozzles. With the $M = 1.4$ nozzle, the radius of the jet after expansion is the nozzle exit, whereas, in the underexpanded case with the $M = 1.0$ nozzle, the nozzle exit acts as the throat. Consequently, the expansion occurs downstream of the nozzle exit, resulting in a larger r_T/r value.

The remaining problem to be considered is how these considerations may be applied to the analysis of the turbulent mixing process. The theoretical analysis of the turbulent mixing previously put forth gives the rate of jet spread with x for a given Mach Number ratio, without consideration of gasdynamic boundary displacements. Using the simple two-dimensional isentropic flow relations, it is possible to predict the change in the average value of r_T most nearly approximating full expansion, based on the throat area of the nozzle and the ratio of the primary stream reservoir pressure to the tunnel static pressure. The results of these computations are listed in Table 2. The primary Mach Number to be used in the theoretical prediction of jet spread must be determined from the ratio of the primary stream total pressure to tunnel static pressure rather than from the primary nozzle geometry. The principal effect of under- or overexpansion is to change the value of r_T and M_1 used in the mixing computations.

TABLE 2

M_1	M_2	P_{s_1}	r_T Experimental	r_T Computed
2.6	1.2	54.5	0.167	0.163
		74.5	0.197	0.197
		94.5	0.214	0.229
1.4	1.4	12.0	0.165	0.167
		14.5	0.178	0.178
		26.5	0.241	0.233
1.8	1.4	19.5	0.159	0.153
		29.5	0.187	0.187
		39.5	0.219	0.219
2.6	1.4	73	0.200	0.200
		91	0.240	0.229
		100.5	0.244	0.244
1.8	1.7	14.5	0.185	0.185
		19.5	0.205	0.218
		29.5	0.244	0.276
2.6	1.7	54.5	0.225	0.225
		84.5	0.298	0.296
		94.5	0.325	0.318

From the above analysis, it would appear that, with an underexpanded supersonic jet, the main effect is to increase the average Mach Number and the average r_T of the jet. The mixing process would be identical to the fully expanded jet but with different flow parameters and a larger value for the average r_T. The amplitude of the oscillatory behavior of the jet would appear to depend almost completely on the reflection ratio, R. The more the ratio differs from unity (indicating strong reflections), the greater the amplitude. The wave length of the oscillation depends on the width or depth of the jet and the Mach Number that would, of course, determine the positions of the reflections. Thus, for any given case with supersonic jet and tunnel streams, the gasdynamic expansions and compressions of the jet may be computed to the required accuracy by any desired method and the turbulent mixing superimposed on the resulting displacement of the jet boundary.

Temperature Effect on Jet Spread

In studying the effect of jet-stream temperature on the behavior of a jet exhausting into a supersonic stream, three different reservoir temperatures were used. These temperatures were 200°, 400°, and 600°F. The experimental apparatus was limited to a maximum jet stagnation temperature of approximately 600°F., consequently jet temperature effects higher than 600°F. were not explored. The effects of temperature can be resolved into two individual problems; one is the effect on the mixing process and the other is the effect on the jet expansions and compressions.

The effect of jet total temperature on mixing is illustrated in Fig. 22, which is essentially plots of the width of the mixing region versus distance downstream for three different jet-stream temperatures. The radius of the jet at $\beta_T = 0.7$ was used because of a more accurate determination of β_T at this point, as explained previously. It is obvious that there is no consistent change in the width of the mixing region within the temperature range explored. The variation appears to be of a random nature, probably caused by experimental inaccuracies in determining r_T. This graph is typical of many that were plotted.

The remaining problem in relation to jet temperature is its effect on the gasdynamics of the jet stream (i.e., the behavior of r_T as a function of x/r). Typical plots of r_T/r versus x/r are presented in Fig. 23. The values of the reflection ratio, R, are noted for each curve. A study of these curves indicates that a change in T_1, which causes the value of R to increase or decrease from unity, increases the amplitude of the oscillations in the jet. For those values of R farthest from unity, the greatest amplitudes are found. This is in complete accord with the results of the previous section.

In summarizing the effect of jet total temperature on jet spread for the temperature range explored, it is indicated that the mixing process between the jet and the surrounding stream is not appreciably altered. The gasdynamic expansions and compressions of the jet were, however, found to vary with jet temperature. The variations appear to be explained on the basis of the variation of the reflection ratio with jet temperature.

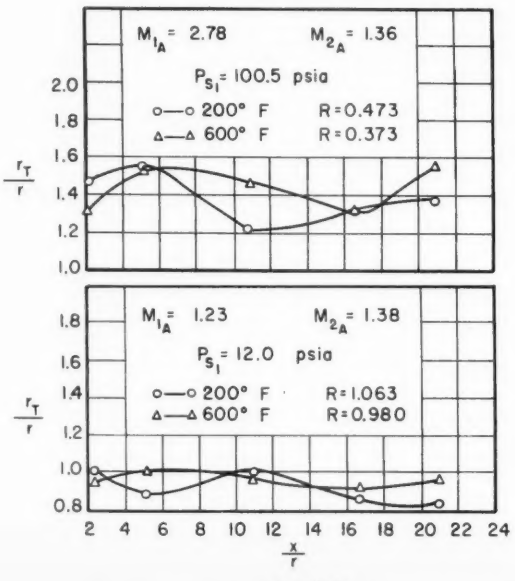


Fig. 23

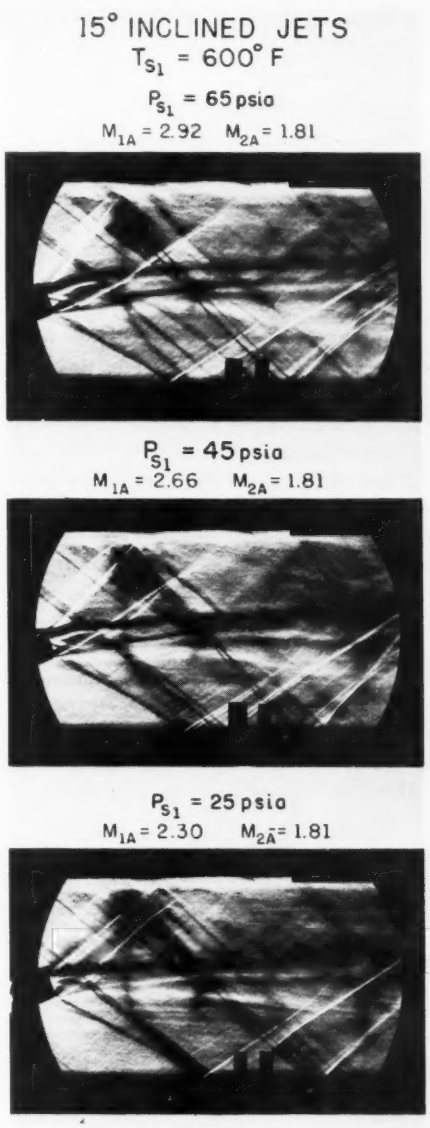


Fig. 24

Wake Studies

To determine in a qualitative manner the effect of relative thick wakes on jet mixing, wedges with the blunt base in the plane of the nozzle exit were attached to one side of the jet nozzle. These wedges had bases of 0.54 and 1.08 nozzle depths. The results of the wake studies may be summarized as follows: The wake behind these relative thick wedges is composed of air from both streams, and the pressure is lower than stream pressure. These factors have the effect of shifting the one-half concentration point, r_T, away from the edge of the primary jet nozzle almost immediately downstream of the nozzle exit. In addition, the rate of mixing is increased. It would also appear that the increase in displacement and rate of mixing are functions of the wake thickness. In evaluating the above, however, it must be borne in mind that the wakes employed were

comparable in size to the jet itself, so that the test cases were extreme.

Inclined Jets

The effects on jet displacement and mixing of inclining the jet stream with respect to the secondary or surrounding stream were studied experimentally with the aid of curved extensions attached to the normal jet nozzles. These extensions produced angular misalignments of 10° and 15° between the two streams.

The jet streams, when inclined to the tunnel stream, behaved about as one would intuitively expect with respect to maintaining the initial inclination. They gradually turned toward zero angle of inclination with the tunnel stream as they progressed downstream. At about 8 nozzle depths downstream, the angle of inclination was only $^1/_3$ to $^1/_2$ the initial angle of inclination. Typical schlierens of a 15° inclined jet are given in Fig. 24.

It was observed that a subsonic jet appeared to spread at a greater rate than normal when inclined, while a supersonic jet actually appeared to contract somewhat. This was observed in surveys as well as in schlieren photographs. However, it must be remembered that the surveys were two-dimensional whereas the physical phenomenon was three-dimensional, and, thus, no conclusions as to an actual contraction or expansion of the stream tube may be made.

Conclusions

(1) The correlation of experiment with the semi-empirical analysis outlined in this paper allows prediction of the spread of a supersonic jet stream exhausting into a supersonic field with the accuracy necessary for design purposes within the range of the experimentation reported.

(2) A supersonic jet in a supersonic stream spreads with distance downstream at a low enough rate to make scavenging practicable.

(3) A strong tunnel normal shock causes rapid deterioration of a subsonic jet stream passing through it and promotes mixing at such a rate as to render almost impossible the problem of scavenging downstream of the shock. The phenomena encountered are similar to those of shock-boundary-layer interaction.

(4) A strong tunnel normal shock has a severe adverse effect on a supersonic jet stream, although it is not as drastic as the effect on a subsonic jet stream.

(5) An oblique shock apparently causes a slight contraction of a supersonic jet stream (accompanied by turning) of the order of magnitude of that predicted by one-dimensional theory.

(6) A supersonic jet stream misaligned with the tunnel stream by as much as 15° apparently suffers no drastic ill effects but is gradually turned parallel with the tunnel stream. The subsonic jet experiences a similar effect but, in addition, exhibits a much greater rate of spread than a comparable jet stream parallel with the tunnel stream.

(7) Wakes induced by bodies having blunt bases of 1.08 and 2.16 nozzle half depths caused an increase in the rate of mixing and jet spread.

(8) An increase of jet-stream temperature (within the range investigated) has little or no effect on jet spread other than the small effect that can be predicted on the basis of the change in the gasdynamic behavior of the jet.

(9) An increase in total pressure in the jet stream over that for full expansion results in a free expansion of the jet stream outside of the nozzle exit, which may be predicted on the basis of gasdynamics and is a good approximation independent of the mixing process.

(10) In general, the jet spread due to turbulent mixing and due to gasdynamics over- or underexpansion appears to be additive effects and may be computed separately to an extremely good approximation.

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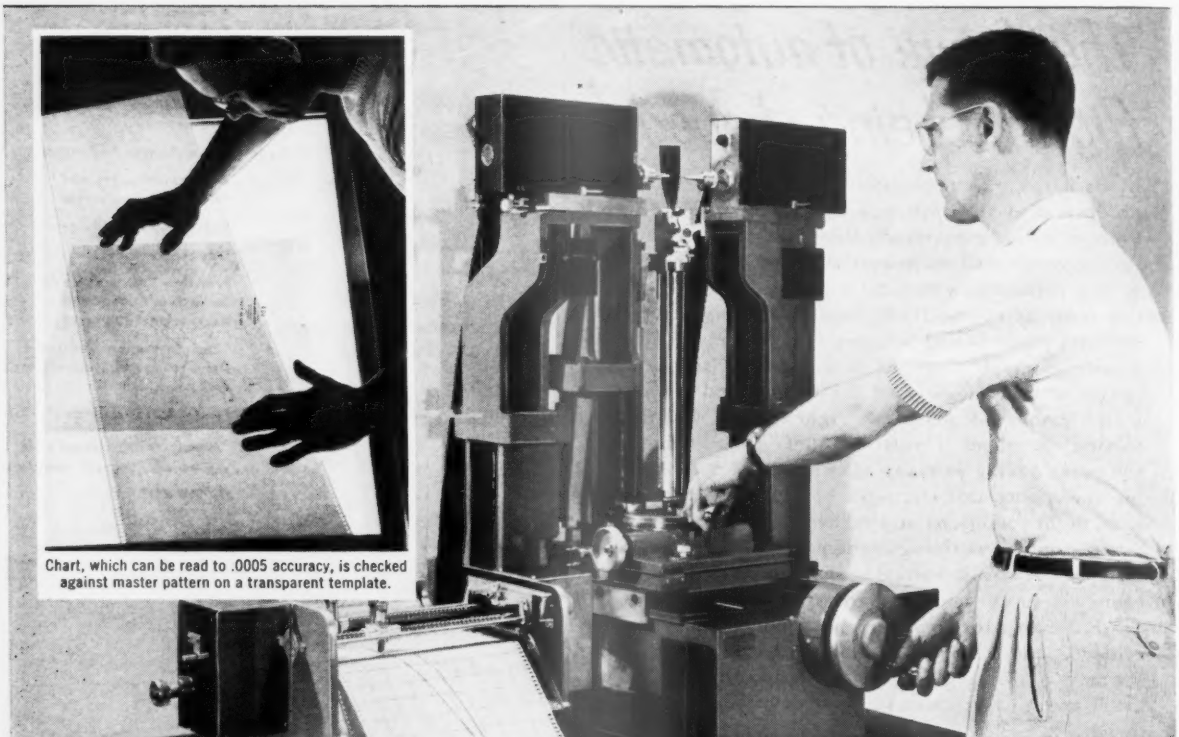

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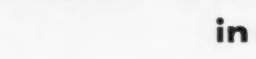

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Two-Dimensional Unsymmetric Flow Patterns at Mach Number 1

By

Gottfried Guderley and Hideo Yoshihara

Wright Air Development Center

Two-dimensional unsymmetric flow patterns at Mach Number 1 are discussed by means of the hodograph representation. As an example, the flow over a wedge profile is investigated and the pressure distribution and the lift curve slope are computed. The results indicate that the value of the lift curve slope at Mach Number 1 is much lower than what would be expected by an extrapolation from the purely supersonic results.

The Effect of Boundary Layer on Sonic Flow Through an Abrupt Cross-Sectional Area Change

By

Robert S. Wick

Jet Propulsion Laboratory, California Institute of Technology

It has long been known that the pressure at the base of high-speed projectiles is lower than the ambient pressure. Since experimental work on projectiles has indicated that the boundary layer definitely affects the base pressure, it was decided to investigate the effect of the boundary layer on the similar phenomena occurring in internal sonic or supersonic flow through a sudden enlargement of cross section.

A two-dimensional flow channel consisting of a convergent section, a straight section, and an enlarged section connected in series was constructed. The flow reached sonic velocity at the end of the throat section and expanded suddenly into the enlarged section. The boundary layer in the throat was varied by changing the mass rate, the pressure, and the length of the throat. The expansion ratio (throat area to expanded section area) was also varied.

The results of these experiments indicated definitely that the pressure in the corner of the expansion was related to the boundary-layer type and thickness upstream of the expansion. A dimensional analysis was used to correlate the results over a range of area expansion ratios and boundary-layer thicknesses, and a "jet-pump" concept was devised which explained qualitatively the effects observed. Means of comparing the results of internal flow over corners and through sudden expansions in area to external flow over corners were also considered.

A Simplified Method to Obtain the Load Distribution Corresponding to the Ackeret Region for Wings Having Arbitrary Source Distribution at Supersonic Speeds

By

Julian H. Kainer

Ryan Aeronautical Company

A simplified approach to the loading on swept and triangular wings of planar and nonplanar form at supersonic speeds was presented which required the potential in the region between the supersonic leading edge and the leading-edge disturbance wave. It is the purpose herein to indicate a simple means of obtaining these potentials and to justify the method with mathematical and physical reasoning. The process involved is inspection.

Plastic Collapse of Thin Rings

By

Chintsun Hwang

University of Notre Dame

When several concentrated or distributed loads are applied on a circular or elliptic ring and are increased proportionally, the ring first yields at some locations and, at the final stage, collapses as a mechanism. The collapse of a ring cannot take place until the number of yield joints developed in the ring exceeds its number of redundancies. In this paper we shall study the configuration of the collapse mechanism, the corresponding collapse load of rings, and the deformations of a circular ring immediately before plastic collapse takes place.

For rings in which the heights of the cross section are small compared with their overall dimensions, the stresses are essentially due to flexure of the ring segments when the ring is under the action of concentrated forces. The stresses due to axial and shear forces are relatively small and may be neglected. Furthermore, at the instant of plastic collapse the deformation of the ring as a mechanism is unlimited if we assume no strain hardening of the material in the plastic state. In parts of the ring where the sections are still elastic, or partly elastic and partly plastic, the deformation is contained and may be neglected. Thus the change in geometry of the ring is disregarded; the ring is considered as a mechanism made of perfectly rigid members connected by yield joints that offer constant resisting moments. The positions of these yield joints and the corresponding collapse load are found for several typical loading conditions.

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See page 48 of August REVIEW for Preprints that are immediately available.

Stall and Surge in Axial-Flow Compressors for Jet Engines

By

M. C. Huppert and W. A. Benser

Lewis Flight Propulsion Laboratory, NACA

Observations of rotating stall have shown that a wide variety of stall patterns is possible.

Hot-wire anemometer data on a multistage compressor have shown a progressive-type stall at low speeds. The amplitude of the flow fluctuations increases in magnitude through the first few stages and then diminishes rapidly to a small value in the latter stages. A stage stacking analysis has shown that rotating stall will exist over a large portion of the compressor map at low speeds but will be instigated almost simultaneously with compressor surge at high speeds.

Blade failures attributable to resonant vibrations excited by rotating stall have

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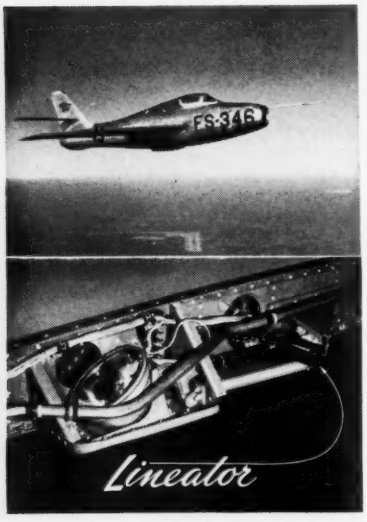

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been experienced in single- and multi-stage compressors.

In the stage stacking analysis no deterioration of stage performance due to unsteady flow resulting from stall of adjacent stages was considered. In general, the pressure drop at the stall point is believed to be much larger than indicated by an analytical formulation of compressor performance. Compressor surge is attributed to a limit cycle operation about the compressor stall point, and, as indicated in a few compressor tests and in jet-engine tests, a small compressor discharge receiver volume may result simply in stall of the compressor without the cyclic characteristics of compressor surge. In this event, engine operation will be limited because of the large drop in performance which accompanies compressor stall.

Preprint No. 414

Turbulence in Supersonic Flow

By
Leslie S. G. Kovásznay
The Johns Hopkins University

First-order perturbation theory indicates that the Navier-Stokes equations for a compressible, viscous, and heat-conductive gas can have three distinctly different types of disturbance fields, obeying three independent differential equations. These three "modes" of disturbance fields are: vorticity mode, entropy mode, and sound-wave mode. The modes are independent when the intensities of the fluctuations are small, but they interact at larger intensities when linearization is not permissible.

The principal tool for measuring the fluctuating fields is the hot-wire anemometer adapted for supersonic flow. In a supersonic flow the hot-wire anemometer responds to two variables: mass flow fluctuations and stagnation temperature fluctuations. The above three modes all contribute to both of these variables. By taking fluctuation measurements at different wire temperatures, the relative sensitivity to the flow parameters varies and a "fluctuation diagram" can be obtained. The character of the fluctuation diagram differs for each mode, and even coexisting modes can be separately determined by analyzing the fluctuation diagram under certain restrictive conditions.

Hot-wire measurements were obtained in various supersonic flows. Pure temperature spottiness (entropy mode) and pure sound-wave fields were explored. Detailed measurements were taken in a turbulent supersonic boundary layer. With the aid of the fluctuation diagram, the intensity of temperature spottiness (entropy mode) and of turbulent velocity fluctuations (vorticity mode) was measured across the layer. Energy spectrum

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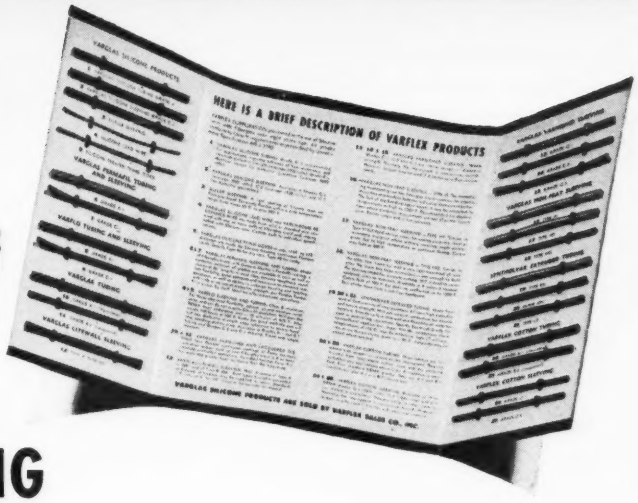

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and probability density measurements gave clues concerning the character of the fluctuations.

Effects of Wing Twist on the Response of an Airplane Encountering a Sharp-Edged Gust

By

Gordon C. K. Yeh and Johann Martinek

Reed Research Incorporated

An analysis is made of the gust response of a simplified model of an airplane having the degrees of freedom of vertical motion and wing twist. A two-dimensional incompressible unsteady flow is assumed. Under the further assumption of linear relation between the wing twist and the vertical acceleration, the equation of motion is set up as a single integro-differential equation and is solved by the method of Laplace transformation with the use of the Faltung theorem. The acceleration responses and alleviation factors are then computed and plotted for a systematic variation of two dimensionless parameters λ and cR, representing the mass ratio and the wing torsional flexibility, respectively. The resulting curves for conventional swept-back wing aircraft show that:

(a) The wing elasticity produces considerable alleviation effects, especially for small values of λ.

(b) It has negligible influence on the time at which the maximum acceleration is attained.

(c) The rate of decrease of the alleviation factor with increase in cR diminishes as cR increases and tends to be constant for large values of λ.

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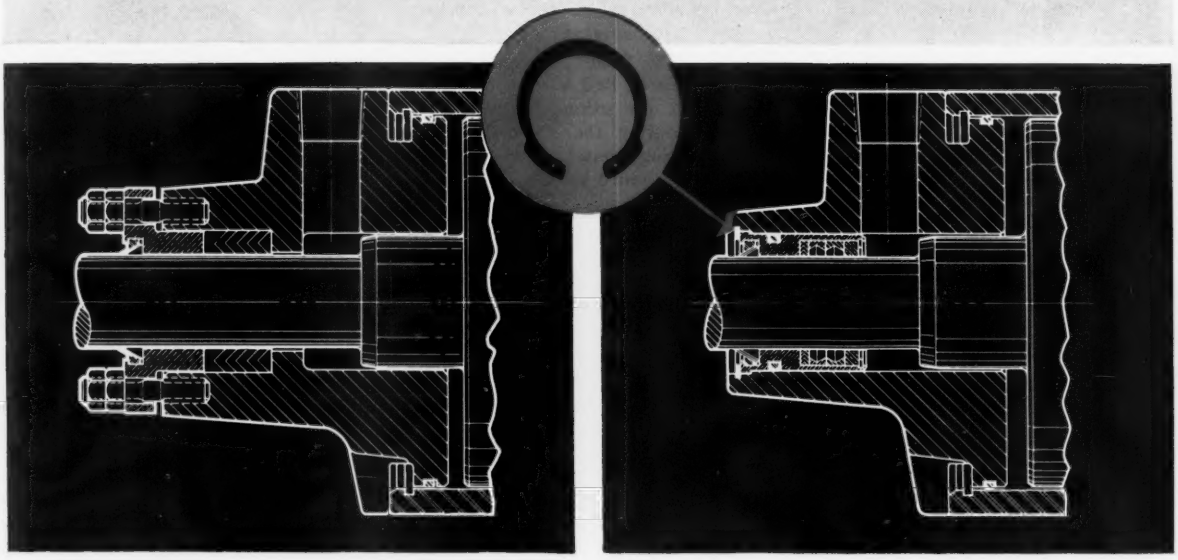

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(*Continued from page 20*)

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▸ **Sir Frederick Handley Page** (HF), Chairman and Managing Director, Handley Page, Ltd., England, was recently appointed Chairman of the Governing Body of the College of Aeronautics at Cranfield, England. Sir Frederick succeeded Air Chief Marshal Sir Edgar Ludlow-Hewitt.

▸ **George E. Harris** (TM) has announced that the sales and engineering representative firm of which he is Founder and President was recently incorporated. The main office of this corporation, George E. Harris & Company, Inc., is located at 1734 N. Hillside, Wichita, Kan.; branch offices are located in Kansas City, Mo.; St. Louis, Mo.; Fort Worth, Tex.; and Cedar Rapids, Iowa.

▸ **W. John Jakimiuk** (M), Director of Design, Société Nationale des Constructions Aéronautiques du Sud Est, France, was Chief Engineer on the SNCASE le Baroudeur S.E. 5000 project. Le Baroudeur is a near-sonic ground-attack fighter designed to take off from a specially constructed and disposable dolly and to land on retractable skids, two main and a small rear one. The S.E. 5000 is powered with the Atar 101 axial-flow turbojet engine.

▸ **Edwin A. Link** (M), President, Link Aviation, Inc., was recently elected President of the Institute of Navigation for 1953–1954.

▸ **Commander Donald B. MacDiarmid,** USCG (M), Commanding Officer, Coast Guard Air Station, Elizabeth City, N.C., has been elected a member of the 1953–1954 Council of the Institute of Navigation. Commander MacDiarmid was the recipient of The Octave Chanute Award for 1950 "for his outstanding contribution to Air-Sea Rescue techniques by scientific analysis and correlation of the effect of wind and waves on seaplanes during landing, maneuvering, and take-off."

▸ **Stanley W. Smith** (AF), Chief Airplane Engineer, Bell Aircraft Corporation, made the second highest score recorded during the Twentieth National Soaring Contest at Harris Hill, N.Y. Mr. Smith earned a total of 1,677 points.

Members on the Move

The purpose of this section is to provide information concerning the latest affiliations of IAS members. All members are, therefore, urged to notify the News Editor of changes as soon as they occur.

Frank M. Anthony (TM), Test Engineer, Jacobs Aircraft Engine Company. Formerly, Stress and Blade Design Group Engineer, Helicopter Division, Bell Aircraft Corporation.

Emmet E. Baker, Jr. (M), now Aviation Sales Engineer, Bendix Radio Communications Division, Bendix Aviation Corporation.

Commander William Bryson, USNR (AM), Navy Member, Staff of Assistant Secretary of State for Public Affairs, Washington, D.C. Formerly, Public Information Officer, Staff, ComAirPac, U.S. Pacific Fleet, Naval Air Station, San Diego.

Herman J. Carpenter (TM), now Lieutenant, Headquarters, Arnold Engineering Development Center, Tenn.

Dean B. George (TM), Project Analysis Group, Design Development Department, The Glenn L. Martin Company. Formerly, First Lieutenant, USAF, Project Engineer, Bombardment Aircraft Branch, Weapons System Division, Deputy for Operations, Wright Air Development Center, Wright-Patterson AFB, Ohio.

Admiral John H. Towers, USN (Ret.), IAS Associate Fellow and Founder Member, has become President of Flight Safety Foundation, Inc. Jerome Lederer, IAS Fellow and Founder Member, who built up the organization, is now the Foundation's Managing Director. Admiral Towers, who retired from the Navy in 1947, was formerly Consultant to Pan American World Airways, Inc.

Kenneth Goldman (TM), Aerodynamicist, Thermodynamics Group, Aerodynamics Department, Aerophysics Division, North American Aviation, Inc. Formerly, Research Fellow, Department of Aeronautical Engineering and Applied Mechanics, Polytechnic Institute of Brooklyn.

Roland L. Guerin (TM), with Engineering Department, Lockheed Aircraft Corporation. Formerly, Captain, USAF, Chief, Airframes Branch, Aeronautical Standards Group, Headquarters, Washington, D.C.

Wallace G. Harkins (TM), Engineer, Marquardt Aircraft Company. Formerly, Engineer Assistant, Northrop Aircraft, Inc.

Harry N. Hill (TM), with Engineering Research Laboratory, North American Aviation, Inc. Formerly, Assistant Chief, Engineering Design Division, Aluminum Research Laboratory, Aluminum Company of America.

Dr. James B. Kelley (M), Director of Research, Physics Research Laboratories, Inc. Formerly, Chairman, Physics Department, Hofstra College.

Charles Klabosh (TM), Flight Test Engineer, Climatics Test Unit, Directorate of Flight and All Weather Testing, Wright-Patterson AFB, Ohio. Formerly, Engineering Assistant, Pratt & Whitney Aircraft Division, United Aircraft Corporation.

Norbert H. Klein (TM), Chief Weights Engineer, Prewitt Aircraft Company. Formerly, Weight Engineer, Kellett Aircraft Corporation.

Emerson W. Conlon, FIAS *(left)*, and Alfred T. Gregory, MIAS, have been appointed to newly created administrative positions at the Fairchild Engine Division of Fairchild Engine and Airplane Corporation. Mr. Conlon, formerly Professor and Chairman of the University of Michigan's Aeronautical Engineering Department, is now Head of Development Engineering. Mr. Gregory, who had been Chief Engineer of Fairchild Engine Division, is now Head of Research and Advanced Engineering.

B.F.Goodrich

B. F. Goodrich brakes cut weight to stop faster airplanes

AIRPLANE BRAKES have a tougher job to stop today's faster-landing airplanes than they did even five years ago! They have to give this improved performance and still be made lighter to allow for increased pay loads—whether it's bombs, people or cargo. Here's how B. F. Goodrich brakes have kept their weight in trim, improved braking efficiency for faster-landing B-52's, the Boeing jet shown above.

The B. F. Goodrich expander tube principle has the basic advantage that braking action applies *equal* pressure over the full circle of the drum, giving greater braking power, better load distribution. Today's B. F. Goodrich brake has a new, narrow-cavity tube that gives even more braking pressure, with *less* fluid.

Another advance in BFG brake design is the new kind of brake block. No rivets are used. The lining is cemented onto a light magnesium shoe. This means that brakes last longer, because more of the lining is used. Elimination of rivets permits full, positive braking down almost to the metal backing.

Landings on the new brakes are safer, smoother. The brakes respond smoothly and quickly to minimum pressure, take emergency overloads better, cannot lock or grab. There are other advantages. Ventilated shoe dissipates heat more rapidly. Retractor spring action eliminates wear due to drag. Relining can be handled with a screwdriver and wrench.

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features: Integral package unit, requires only simple power source and reservoir connections . . . operates 500 hours continuous duty per Specification MIL-C-7135 . . . used extensively in military aircraft pneumatic systems . . . easy to install and service . . . takes less than five minutes to install or remove entire package unit. *Approved by U. S. Navy for installation in military aircraft.*

See Rhodes Lewis for these new light-weight products and systems

ITEM	Used in high-pressure pneumatic systems	Used in low-pressure pneumatic systems	Other aircraft applications
AC & DC Compressors	X	X	
Hydraulically Driven Compressors	X	X	
Bleed Turbine Compressors	X	X	
Fiberglass Pneumatic Receivers	X	X	
Electrical & Electronic Control Systems			X
AC & DC Motors	X	X	X
Small Accessory Turbine Drives	X	X	X
Pneumatic Valves, Operated Electrically or Mechanically	X	X	
Solenoids, Intermittent or Continuous Duty	X	X	X
Pneumatic Ejection Systems	X	X	

Take advantage of Rhodes Lewis engineering knowledge and manufacturing facilities in the field of electrical and pneumatic equipment. Your inquiries are cordially invited.

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ELECTRIC PNEUMATIC ENGINEERS·MANUFACTURERS

B-3300

Dr. Donald H. Loughridge (AF), Dean, Northwestern Technological Institute. Formerly, Assistant Director, Reactor Development Division, Atomic Energy Commission.

Walter F. McGinty (AF), Engineering Manager, Transco Products, Inc. Formerly, Staff Engineer, Transco.

Dr. Angelo Miele (M), Research Assistant Professor, Polytechnic Institute of Brooklyn. Formerly, Research Associate, Brooklyn Polytechnic.

Philip F. Oestricher (TM), Aerodynamics Engineer, Fort Worth Division, Consolidated Vultee Aircraft Corporation. Formerly, Graduate Student, Aeronautical Engineering Department, University of Florida.

Edward M. Owen (M), Assistant Director of Military Relations, Northrop Aircraft, Inc. Formerly, Director, Flight Department, Northrop.

Paul J. Papanek (M), Eastern District Manager, Marquardt Aircraft Company, Dayton, Ohio. Formerly, Sales Manager, Aircraft Products, Royal Electric Incorporated.

Thomas G. Preston (M), Vice-President and General Manager, Stratoflex of Canada, Inc., West Toronto, Canada. Formerly, General Sales Manager, Prenco Progress and Engineering Corporation, Ltd., Canada.

Michael K. Rastiello (TM), Production Design Engineer, The Glenn L. Martin Company. Formerly, Design Engineer "A," Tri-State Design, Inc.

Stuart L. Rich (AM), General Manager, Cazenovia Precision Machine Company, Inc. Formerly, Manager, Government Contracts, Glowmeter Corporation.

Richard A. Smith (TM), Stress Analyst "A," Aircraft Division, Kaiser Metal Products, Inc. Formerly, Stress Analyst "A," Northrop Aircraft, Inc.

Max R. Stanley (M), Director, Flight Department, Northrop Aircraft, Inc. Formerly, Assistant Director, Flight Department, Northrop.

William G. Street (AF), Staff, Design Development Department, The Glenn L. Martin Company. Formerly, Project Chairman, Operations Research Office at The Johns Hopkins University, U.S. Army.

William B. Terry, Jr. (TM), Assistant Administrative Engineer, Flight Refueling, Inc. Formerly, Engineer, Petro-Chemical Development Company, Inc.

Robert K. Wead (M), Head, Application Engineering Department, Marquardt Aircraft Company. Formerly, Chief Project Engineer, Marquardt.

Paul E. Whisenhant (AM), Engineering Illustrator, Allison Division, General Motors Corporation. Formerly, Engineering Illustrator, Fort Worth Division, Consolidated Vultee Aircraft Corporation.

James J. Wilder (M), Chief of Quality Control, Flight Refueling, Inc.; Formerly, Major, Chief, Quality Control Office, Maintenance Engineering Division, Air Materiel Command, USAF.

Quick control response all the time with

HYCO-SPAN *Control Cables*

PUT yourself in a jet pilot's seat. You're whistling along faster than sound . . . up around 30,000 or 40,000 ft. Then you want to change course. Rudder and air foils must respond *instantly* when you move the controls. They will, if your plane is equipped with American Hyco-Span Aircraft Cables.

These cables expand and contract right along with the airframe, regardless of what the air temperature is. They have a higher coefficient of expansion than either carbon or stainless steel cables. So they stay tight and firm . . . prevent mushy controls and dangerous flutter.

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Hyco-Span Cables are non-magnetic and have corrosion resistance equal to stainless steel.

For complete technical information, send the coupon.

Important advantages of HYCO-SPAN Aircraft Cables

1. Stay tight and firm—even at minus 70°F.
2. Simplify cable rigging — no temperature compensating devices needed on large planes.
3. Last longer, because cable tension can be reduced and corrosion resistance is equal to stainless steel.
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5. Are non-magnetic, so do not affect accuracy of electronic instruments.

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UNITED STATES STEEL

Corporate Member News

• **Aircraft Radio Corporation . . .** A two-way ground-air VHF radio equipment, known as Type 12 Portable Communicator (VHF 118–148 mc.), is now being manufactured by Aircraft Radio. The weight of this unit, including the carrying case, is 36.7 lbs.

• **AiResearch Manufacturing Company . . .** *Booklet No. EB-3-1*, recently published by AiResearch, outlines the operating principles of AiResearch induction generators for aircraft and guided missiles. The booklet is illustrated with charts and photographs and contains descriptions of design features, operating function, performance characteristics, and applications of the company's generators. It is available through the Los Angeles office.

• **Beech Aircraft Corporation . . .** According to a recent report, Beech is now building the Beechcraft Model D18S transport and the Bonanza for commercial customers, the SNB trainer-transport for the Navy, the C-45G and T-34A for the USAF, and the L-23A for the Army Field Forces.

• **Bendix Radio Communications Division, Bendix Aviation Corporation . . .** A new glide slope receiver, the MN-100A that provides 20 channels in the frequency range of 329.3 to 335.0 mc., is now being marketed. Selection of the desired frequency on this unit is accomplished by means of a VOR-localizer-glide slope control selector, also used in conjunction with Bendix NA-5 Distance Measuring Equipment. The MN-100A weighs less than 13 lbs. . . . The development of a new flush-mounted magnetic loop antenna for use with the Bendix radio compass was recently announced. Bendix engineers have stated that this antenna has a sensitivity equal to, or greater than, the present MN-60 and MN-36 loops and that it will weigh about half as much. It is scheduled to be available for commercial and military aviation in the spring of 1954.

• **Boeing Airplane Company . . .** The KC-97G is now being delivered to the USAF. These ships, eleventh model of the Stratofreighter series, can be used as Flying Boom aerial refueling tankers and as multi-purpose cargo, personnel, and hospital air evacuation transports. The new KC-97G, through the relocation of the aerial refueling tanks, can carry cargo items without removal of the refueling equipment. The KC-97G also has provisions for the installation of external fuel tanks. . . . A $283,018 fuel tank test laboratory is now under construction at the north end of Boeing Field, with completion scheduled by next February. This new facility, paid for by the Air Force and built by Boeing as a prime contractor, will include a building for a slosh and vibration test table, a stand test building for determining the weathering properties of fuel tanks, a laboratory building complete with facilities for refrigerating and testing fuel tanks to a temperature of −85°F., and a boiler house. The slosh and vibration test table is designed to test full fuel tanks weighing up to 50,000 lbs. The table will tilt 15° and will vibrate at various frequencies and amplitudes, both adjustable during operation. A large paved apron for outdoor tests is also planned, as are underground fuel tanks and a fuel distribution system. . . . A Manufacturing Research Unit that conducts independent research, works out entire processes, and builds sample tools and fixtures has been formed in Boeing's Tool Engineering Department. . . . A new engineering and cafeteria building, which will cost approximately $850,000, is being erected at Boeing's Wichita Division. . . . A Board of Directors meeting was called on July 23 as a result of the death on July 4 of Harold E. Bowman, Boeing's Secretary-Treasurer. At this meeting, Evan M. Nelson, formerly Seattle Division Controller, was elected Treasurer; Clyde Skeen, formerly Assistant Controller, was elected Controller; James E. Prince, Vice-President—Administration, was given the additional duties of Secretary; J. O. Yeasting, formerly Vice-President—Controller, was made Vice-President—Finance; and Paul Ford was named Seattle Division Controller.

The development of a new hand-held camera (above) for front-line aerial reconnaissance, designated the K44, has been announced by Fairchild Camera and Instrument Corporation and the USAF Air Research and Development Command. For further details, please refer to the Fairchild Camera item on this page.

• **The Cessna Aircraft Company . . .** The second Model 310 Cessna, a small twin-engined executive transport, made its first flight the early part of the summer. By using both of the existing Model 310's, the overall test period is expected to be shortened, thus permitting the production line to start in the early part of 1954.

• **The Cessna Aircraft Company, Continental Motors Corporation, and The Goodyear Tire & Rubber Company . . .** According to a recent announcement, a "revolutionary" propeller V-belt drive has been developed. This propeller drive system was tested on a Cessna 170 powered with a C-145 series four Continental engine turning a modified McCauley propeller. This propeller, manufactured by McCauley Propeller Company, was 92 in. in diameter with a 70° pitch. This system is said to produce a minimum of engine and propeller vibration, a lower noise level inside and out, and greater efficiency from a larger, steeper pitched, and slower turning propeller.

• **Chance Vought Aircraft Division, United Aircraft Corporation . . .** An engineering design facility was established in Boston on August 1 to handle general design work on some of the division's missile and fighter design projects. (Selected portions of Chance Vought's present backlog of engineering work is being assigned to this new facility.) The establishment of this Boston facility is expected to enable the division to meet the problems created by a shortage of engineering personnel, which, while general throughout the industry, is said to be particularly acute in the Southwest.

• **Consolidated Vultee Aircraft Corporation . . .** L. W. Miller has submitted his resignation as Vice-President—Finance, effective November 30. Until a successor is elected to this post, G. T. Bove, Treasurer, and D. T. Fisher, Controller, have assumed Mr. Miller's duties.

• **Cornell Aeronautical Laboratory, Inc. . . .** The first supersonic flight ever made by the laboratory was made the early part of last summer in an F-86 Sabre piloted by John C. Seal, the Laboratory's Chief Test Pilot. Mr. Seal, who was the recipient of the Institute's Octave Chanute Award for 1952, passed Mach 1 during a steep dive made from 43,000 ft.

• **Douglas Aircraft Company, Inc. . . .** A new low-speed wind tunnel has been built at the Santa Monica plant for aerodynamic, power-plant, and air-conditioning work. The tunnel measures 65 ft. in length and 25 ft. in width and is housed in a building that is 40 by 80 ft. The tunnel's test section is 3 ft. high, 4.5 ft. wide, and 10 ft. long. . . . A pamphlet entitled *Flight Fitness* has been prepared by the Engineering Department of Douglas's El Segundo Division to familiarize the pilot with certain factors affecting the human body which will assist him in carrying out flight missions safely and efficiently. Those who contributed to this publication are: M. F. Fansler, Engineer and Pilot; C. F. Lombard, Ph.D.; J. R. Poppen, M.D., and Walter A. Durnin, Jr., Art. Dr. Poppen, an IAS Member, is Consultant in Aviation Medicine at the El Segundo plant. . . . Following an action of the company's Board of Directors by which that body was increased from 13 to 15 members, Donald W. Douglas, Jr., Vice-President—Military Sales, Nat Paschall, Vice-President—Commercial Sales, and Stanley G. Welsh were elected Douglas Directors. One vacancy had been created through the resignation of William E. Douglas.

• **Eclipse-Pioneer Division, Bendix Aviation Corporation . . .** Plant No. 2, adding 103,250 sq.ft. to Eclipse-Pioneer's manufacturing facilities, has been constructed at Teterboro, N.J., to relieve heavy pressure on the division's main manufacturing plant located nearby. This is the largest single expansion of Bendix' North Jersey manufacturing facilities since 1942.

• **Fairchild Camera and Instrument Corporation . . .** The recently announced K44 hand-held camera, designed by Fairchild for front-line aerial reconnaissance from

SPECIALIZED POWER from FAIRCHILD

JET POWER for a guided missile . . . take-off boost for a commercial or military transport . . . main power source for a piloted plane . . . these are potential uses for the Fairchild turbojet engines.

The J-44, now in production, was the first choice for the new high-speed, high-altitude Ryan Firebee target drone. This engine design, proving its worth *today*, has unlimited possibilities for *tomorrow*.

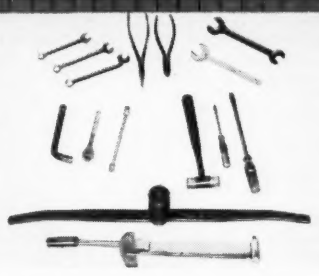
* * *

FAIRCHILD'S monocoque construction is another important development by an organization with over 25 years of power plant experience. Working for all three branches of the services, this development and production team is looking ahead to meet the challenge of *specialized power* on land, in the sea, and in the air.

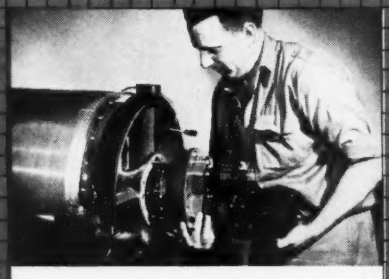
J-44 SPECIFICATIONS

Announced thrust	*1000 lbs*
Weight	*300 lbs*
Length	*72 inches*
Diameter	*22 inches*

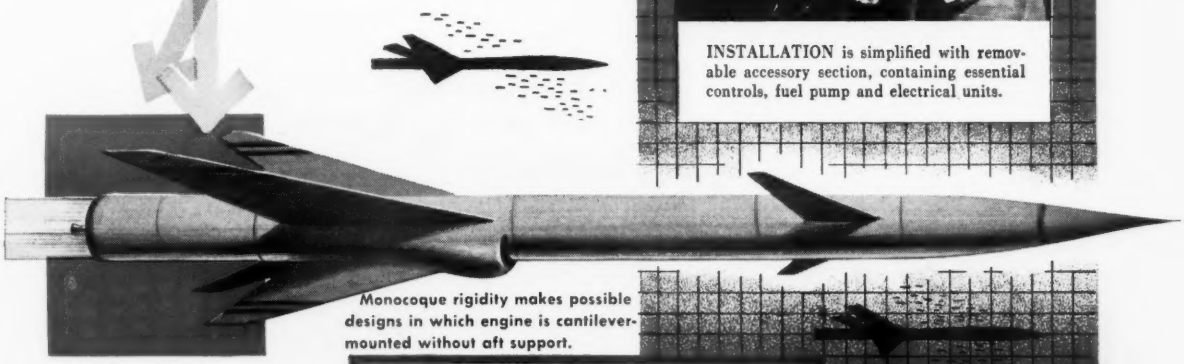
PRODUCTION, with unique monocoque construction, minimizes heavy castings and machined parts, speeds up manufacturing.



OVERHAUL and service is simplified — shown are only tools required for complete assembly or dissembly.



INSTALLATION is simplified with removable accessory section, containing essential controls, fuel pump and electrical units.



Monocoque rigidity makes possible designs in which engine is cantilever-mounted without aft support.

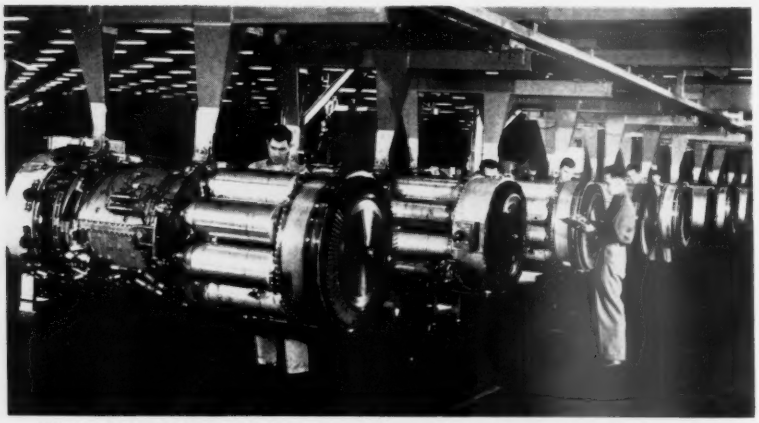
ENGINE AND AIRPLANE CORPORATION

FAIRCHILD

Engine Division

Farmingdale, L.I., N.Y.

Aircraft Division, Hagerstown, Md.
Guided Missiles Division, Wyandanch, L.I., N.Y.

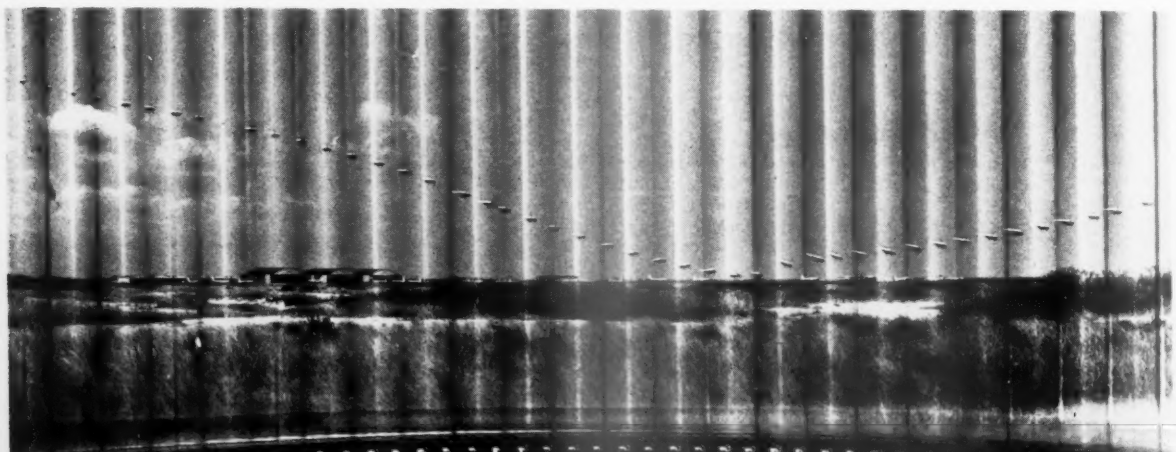


What may be this country's first completely mechanized jet-engine conveyer system was recently installed at the General Electric Company plant near Cincinnati. This production-line picture shows a part of that system, with J-47 jet engines hanging batlike from an overhead conveyer. This new system permits the J-47's to be moved automatically from station to station, thus allowing the worker to concentrate fully on assembling the engine parts.

U.S. Army liaison planes, has completed tests at the Air Force's Air Research and Development Command and was delivered in midsummer to the Army for further testing. The shutter on the K44 is a new version of the corporation's "Rapidyne" design; speeds of 1/50, 1/100, 1/200, and 1/400 sec. are possible. The camera may be operated manually with a forward and backward movement of the right-hand grip, or, by flipping a switch and connecting a plug, it becomes semi- or fully automatic and can take sequence pictures at the rate of 75 per min. Using 50-ft. rolls of 5-in. film, the K44 can take any number of exposures that can be cut off with a built-in knife arrangement, wound into its special film cassettes, and dropped by a small parachute for immediate development by the front-line ground forces. A 6-in. f/4 lens mounted in a metal cone can be supplemented with a 12-in. lens for telephoto requirements. Both shutter and aperture controls are set by dials mounted on the exterior of the lens cone. (See photo on p. 80.)

• **General Electric Company . . .** The second edition of G-E's *Measuring Equipment for Laboratory and Production Testing Including Radiation Instruments* is now available from the Schenectady, N.Y., office. This fully illustrated publication, GEC-1016A, contains information on products ranging from simple current indicators to completely automatic oscillographs, from surface roughness scales to mass spectrometers, and from d.c. amplifiers to radiation monitors. . . . Two new bulletins on G-E's aircraft generator systems are also available. One of the two bulletins, *28 Volt DC Generator Systems for Aircraft*, outlines the advantages of using a complete system. Photos and descriptions of each component part of the system are also included. The other bulletin, *AC Generator Systems for Aircraft*, shows, among other things, photos and detailed descriptions of three-phase alternators, static generator regulators, and control panels.

• **The B. F. Goodrich Company . . .** A new thermal-insulating material has been developed by Goodrich at the Defense Department's request for use in the rocket and guided-missile field. This insulation, known as "Pyrolock," can be sprayed on clean metal surfaces, adhering to them



A pictorial record of the flight path of a helicopter during a normal landing and take off (at New York International Airport) is shown in this multiple-image picture taken with the Fairchild Model IV-A Photographic Flight Analyzer. This Analyzer was developed by Sherman Fairchild & Associates, Inc., of which Sherman M. Fairchild, IAS Fellow, Founder Member, and Benefactor, is Founder and President. Designed for daylight lighting conditions, it will freeze target motion at speeds up to 600 m.p.h. It uses a special 8- by 10-in. photographic glass plate divided into approximately 58 narrow vertical frames, each of these strips being exposed in sequence as the aircraft passes within the range of the camera's wide-angle lens. A built-in timing device, shown in the lower part of the picture, records the time intervals to an accuracy within 0.001 sec. on each exposure. One method of determining the scale of the resulting picture is by a simple geometric relation between (1) the known offset distance of the Analyzer from the flight path and (2) the focal length of the lens. Thus, if the instrument is offset 1,000 ft. from the flight course with a 6-in. (or 0.5-ft.) focal-length lens, the scale of the recording is 1,000:0.5 or 2,000:1.

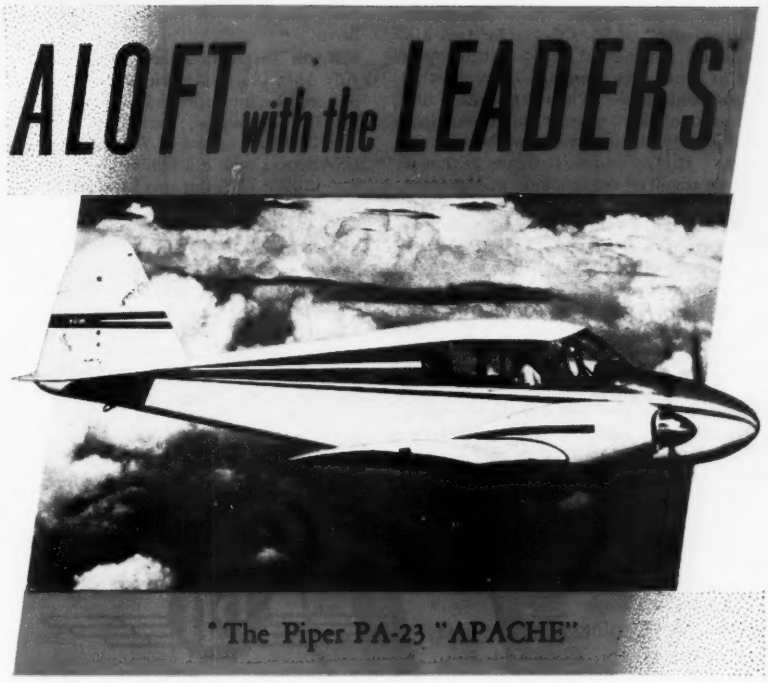
without using either sandblasting or priming-surface preparations. Metals treated with a $^1/_{16}$-in. coating of Pyrolock are said to be protected for as long as 10 sec. against flame temperatures hotter than their various melting points. According to company claims, this nontoxic nonflammable and nonexplosive material is resistant to most solvents and chemicals and can withstand indefinitely temperature cycles of −60° to +165°F.

• **The Goodyear Tire and Rubber Company . . .** A streamlined model of the World War II intermediate-range K-type airship is now under construction at Goodyear Aircraft Corporation's Wingfoot Lake Airship Base near Akron, Ohio. This new model, known as the Goodyear ZP4K, has a capacity of 527,000 cu.ft., a 15.5 per cent increase in capacity over the original "K" ships used by the U.S. Navy in the Anti-Submarine Warfare units. The ZP4K will be equipped with the latest ASW devices and will be powered with two radial air-cooled engines mounted on outriggers and driving two 11-ft., 6-in., three-bladed full-feathering controllable-pitch reversible propellers. It will have a top speed in the neighborhood of 65 knots and will be able to maintain low speeds or to hover practically motionless on the track of undersurface craft. The blimp's flight controls will be subject to manual or automatic-pilot operation. Although the number of new ZP4K airships under construction was not disclosed, it was said that Goodyear Aircraft is also building a number of larger and longer range "N"-type nonrigid airships for the Navy's ASW.

• **Lockheed Aircraft Corporation . . .** The first production model of an automatic ejection seat using telescoping guide rails to "steer" it out of the cockpit was put on display last August 3. These guide rails are composed of two specially constructed sections, each about 3 ft. long, which guide the seat up to 48 in., instead of the 28 in. of previous types. This extra length permits the seat to be guided well above the top of the cockpit sill and is said to give the seat a high trajectory after ejection, thereby gaining additional clearance over the airplane. This new ejection seat is now being factory installed in the Lockheed F-94C Starfire.

• **Marquardt Aircraft Company . . .** An Application Engineering Department has been established at Marquardt with R. K. Wead, MIAS, as its head.

• **The Glenn L. Martin Company . . .** A rotary bomb door from which bombs and rockets have been successfully launched at high speeds has been patented by two Martin Armament Engineers, Werner Buchal and Albert T. Woollens. This patent, No. 2,634,656, has been assigned to the Martin Company. Immediately prior to bomb release, the new preload door rotates 180° to operating position, with the bombs then becoming externally carried stores. Except for the time involved in turning this door from one position to the other, there is no opening in the fuselage, hence no buffeting or turbulence in the bomb bay area and no need to slow down the airplane to obtain the required stable platform. The Martin rotary bomb door is also said to prevent "tumbling" of the



In the category of personal aircraft,
there is no name better known than *Piper.*
Leading the trend in this field
toward faster, safer, roomier planes
is the new twin-engined Piper PA-23 "APACHE".
For this sleek ship — practical for
night flying under instrument control —
Electrol engineers integrated their
technical skill with that of
Piper designers to build
the necessary hydraulic components.
This same coordinated effort is at the
disposal of all aircraft manufacturers.

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bombs by having each bomb or cluster "kicked out" of its shackle by two air-actuated plungers that are aided by a radius arm. The door itself is removable from the airplane. When out of the plane, it is mounted on wheels and raised into position by using three standard bomb hoists. It is fitted into its place so that it can be revolved on trunions at the front and rear ends. With larger sizes of bombs, the load may be split, two being carried on the bottom of the door as external stores at the start of the flight. After these two bombs have been released, the door is revolved to permit those that have been carried internally to be released . . . . The first USAF B-57 night fighter, manufactured by Martin, made its maiden flight on July 20. The B-57 was developed from the basic design of the English Electric Canberra.

• **North American Aviation, Inc.** . . . On July 16 a North American F-86D Sabre, powered by an improved General Electric J47-17 jet engine, established a new world's speed record of 715.697 m.p.h. in USAF tests over a 3-km. course at Salton Sea, Calif. The pilot was Lt. Col. William F. Barns, Air Materiel Command representative at North American's Los Angeles plant. The time in each of the four required passes over the measured course was 720.574, 710.514, 721.351, and 710.350 m.p.h. The four runs, two in each direction, were made between the prescribed maximum and minimum altitudes of 1,640 ft. (500 meters) and 328 ft. (100 meters). Smoke markers indicated the start and finish of the course. The record flight was conducted under the rules of the Fédération Aéronautique Internationale and the National Aeronautic Association. . . . An engineering flight-test hangar, now being constructed on the north side of the Palmdale Airport, Calif., is part of the USAF development at that field; it will be owned by the U.S. Government and will be leased to North American. When this 360- by 220-ft. hangar is completed, North American is planning to transfer to Palmdale that part of its engineering flight test operations now located at Edwards AFB, Calif. . . . According to a July 8 announcement, the prototype of the USAF F-100 supersonic turbojet-powered fighter successfully completed its first test flights. This North American fighter, powered by a Pratt & Whitney J-57 jet engine, is now in production at the company's Los Angeles plant. . . . The other successful first flights of two North American-designed aircraft were announced in midsummer. One was an F-86 Sabre built under license by Commonwealth Aircraft Corporation in Australia and powered by a British Rolls Royce Avon engine. The other aircraft was the prototype of the North American FJ-3 Fury, powered by the Wright J-65 Sapphire. The FJ-3 is being produced at the company's Columbus Division. . . .

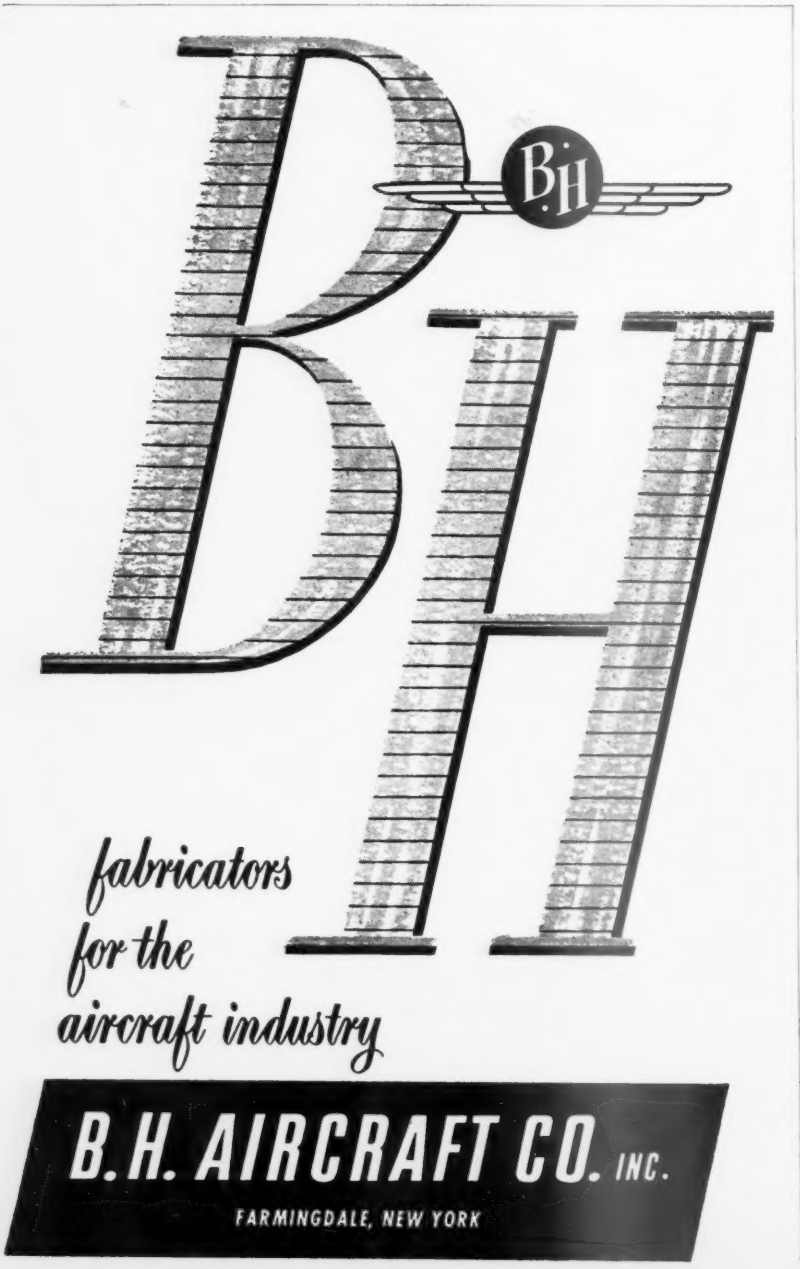
• **Northrop Aircraft, Inc.** . . . A special Titanium Committee has been established at Northrop to determine not only the possibility of using titanium in current and future design projects but also whether each proposal is economically sound.

• **The Parker Appliance Company** . . . In line with Parker's expansion program, Reginald P. MacDonald has been named Sales Engineer for the company's new Engine Accessories Division. Mr. MacDonald, who was formerly with General Electric Company, will specialize in jet-engine components.

• **Republic Aviation Corporation** . . . The last of 4,457 Thunderjets built for the U.S. Air Force was delivered on July 27. Republic's production lines are now being devoted entirely to volume output of the Thunderjet's successor, the swept-wing F-84F Thunderstreak.

• **Simmonds Aerocessories, Inc.** . . . The Electronics Engineering Department has been expanded to include a communications development project. This new engineering project is located at the Simmonds Development Center at Tarrytown, N.Y.

• **Solar Aircraft Company** . . . According to a recent company release, the nation's first conveyorized mass-production facility built for applying high-temperature ceramic coatings to alloy steel components has gone into operation at the San Diego plant. This 4,000-sq.ft. installation, representing an investment of more than $150,000, is said to cut coating time in half on critical jet-engine parts. This facility, now being used to coat inner combustion chambers and transition liners for General Electric Company's J-47 turbojet engines, is able to handle 5,000 combustion chambers and an equal number of the transition liners per month on a single-shift operation and with a working force of 12 employees.



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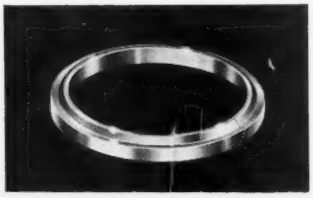

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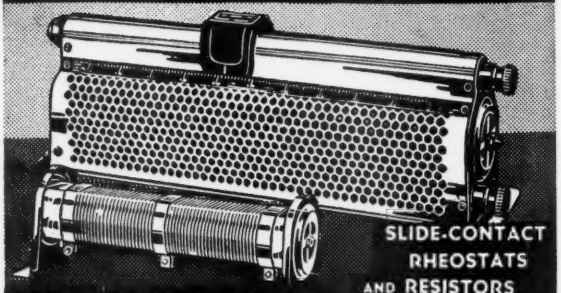

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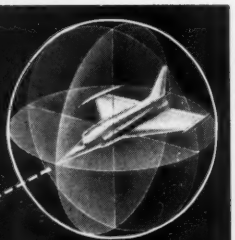

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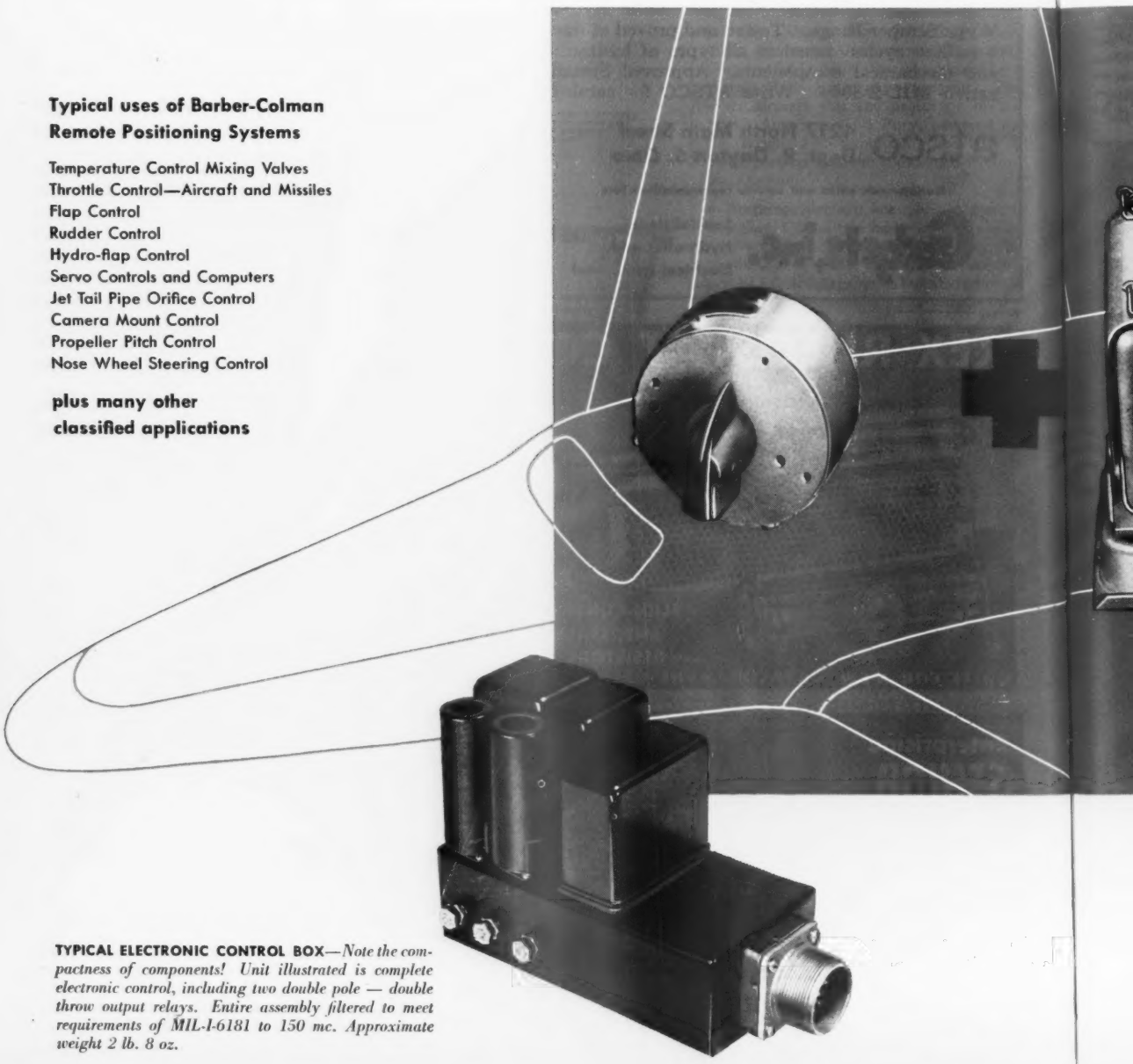

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Each is a *complete* system. Listed below in order of increasing accuracy, outstanding features of each are as follows:

BASIC REMOTE POSITIONING—Ideal for moderate speed control applications. Basically a d-c bridge with transmitting and receiving rheostats. Actuator is energized by null-seeking polarized relay which detects unbalance signal. Simplicity and ruggedness are important features for long life and ease of maintenance.

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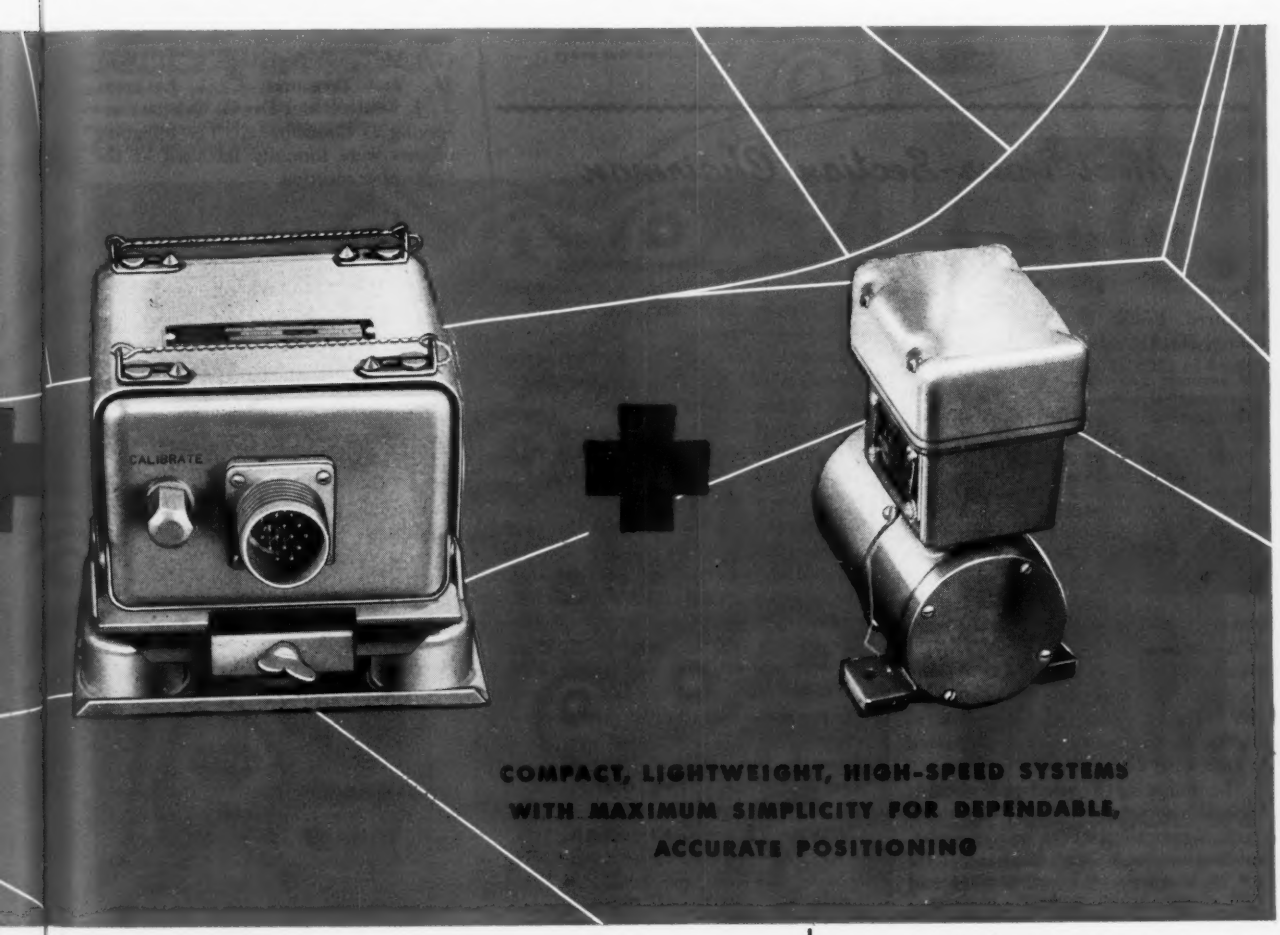
Whenever you have a need for remote positioning controls, consult Barber-Colman engineers for the system best suited to your application. Send coupon below for details.



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• **The H. I. Thompson Company . . .** The name of this firm, manufacturers of insulation products, has been changed to H. I. Thompson Fiber Glass Company.

• **Trans World Airlines, Inc. . . .** A. V. Leslie has rejoined TWA as Vice-President—Finance and Treasurer. Mr. Leslie, who left TWA in 1950 after serving for 3 years as Vice-President and Treasurer, served during the interim period as Vice-President of Hughes Tool Company. Mr. Leslie succeeds Erle M. Constable as Treasurer. Mr. Constable resigned to accept an executive position with an aircraft manufacturing company.

• **United Air Lines, Inc. . . .** A new 90,000-sq.ft. air-line building, erected by the City of Denver, Colo., with CAA support and leased to United for a 30-year period, was occupied by United on July 16. This $1,284,000 structure, which forms the northwest wing of the Denver terminal building, is now functioning as the company's Flight Operations and Transport Services headquarters. . . . A six-bay hangar and a 68,000-sq.ft. operations building to be built at New York International Airport by the Port of New York Authority have been leased to United for 20 years with an option for renewal at the end of that period. The hangar will be able to accommodate simultaneously four twin-engined and six four-engined aircraft of the types now flying or to be built in the future. Occupancy of these $5,000,000 facilities is scheduled for the spring of 1955.

• **United Aircraft Corporation . . .** A license to manufacture the Hamilton Standard Cold-Air Unit for turboprop and turbojet aircraft has been granted to de Havilland Propellers Limited, of England. The license permits the sale of these refrigeration units for use in British aircraft throughout the British Commonwealth and in certain other countries.

Meet Your Section Chairman

Alfred F. Stott

Chicago Section

Alfred Frank Stott, a native of Grand Rapids, Mich., completed grade school in 1925 at Appleton, Wis. Four years and four schools later, he was graduated from the Bay View High School in Milwaukee. September of that year, 1929, found him in Los Angeles as an aeronautical engineering student at the Western College of Aeronautics, since taken over by the Hancock College in Santa Maria, Calif. By taking day and night classes, he was able to finish the required work in slightly over 2 years and was graduated in December of 1931.

The following February, Mr. Stott became associated with the Milwaukee Parts Corporation where he was Assistant Engineer and Chief Mechanic. He left their employ in April of 1935 and joined the faculty of The Aeronautics Academy, Inc. He is now Dean of Engineering in the Academy's Engineering School and Chief Instructor in the Mechanics School. His time at the Academy is divided among preparing the curriculums for the Engineering and Mechanics schools, teaching in both schools, being in charge of all school personnel and student placement, and serving as Faculty Adviser to the Academy's IAS Student Branch.

From 1939 to 1943, a Mechanics Training Program was conducted at the Academy for USAAF enlisted personnel. For this program, Mr. Stott served as Assistant Director of Training and Personnel Director. He was also active during World War II in selective service and war man-power problems.

Mr. Stott lists three "most interesting episodes" of his career. While all three are important, the first one definitely overshadows the other two.

Concerning the first event, he says, "I have had a lot of really happy and interesting experiences, but probably the one that closest affected me was my marriage to one of my pupils [Martha Jane Allyn] upon completion of her aeronautical engineering course. I believe she was one of the first girls ever to receive a degree in aeronautical engineering." Their marriage took place on June 26, 1937, and they are now the parents of two boys, Jim, aged 13, and Tad, aged 10, and of two girls, Carol, aged 8, and Laura, aged 6.

As the second "most interesting episode" he lists "the wonderful times I have had and friends I've made as a result of my Chicago IAS Section work." His third one consists of "being lucky enough to play Goalie on a State Championship High School Soccer team while in my freshman year."

For the past 18 years, Mr. Stott has held active CAA certificates as an Airplane and Engine Mechanic, a Ground Instructor, and a Parachute Rigger. He was an active pilot from 1927 through 1936.

IAS Sections

Dayton Section

W. Donald Dodd, Jr., *Secretary*

The 1952–1953 season of the Dayton Section was concluded on May 27 with an excellent dinner meeting and a plant tour of Aeronca Manufacturing Corporation. The tour was arranged by Ed Ledeen, of the Program Committee. It included interesting insights into the lofting, die pattern, master gage press, and stretch-forming departments and ended in the assembly shop where the many components are put together to form the finished product.

▶ The following persons were elected to office for the 1953–1954 season: Chairman, Charles L. Hall; Vice-Chairman, G. J. McTigue; Secretary, W. D. Dodd, Jr.; and Treasurer, C. I. Lathrem. T. J. Keating and Dr. G. Graetzer are serving as Councilmen. The foregoing officers were formally installed at the September meeting.

New York Section

Frederick K. Teichmann, *Chairman*

The following slate of officers was elected for 1953–1954: Chairman, Frederick K. Teichmann; Vice-Chairman, Charles Tilgner, Jr.; and Secretary-Treasurer, Theodore F. Hammen, Jr. Members of the Advisory Board are: C. E. Pappas; Bruce G. Eaton, Jr.; Scott Flower; Norman L. Winter; Kenneth Campbell; Nicholas J. Hoff; Clayton C. Shangraw; and R. Paul Harrington. Jerome Lederer is the Section Representative to the Nominating Committee for Area Councilors.

Ottawa Aeronautical Society

H. C. Oatway
Outgoing Secretary

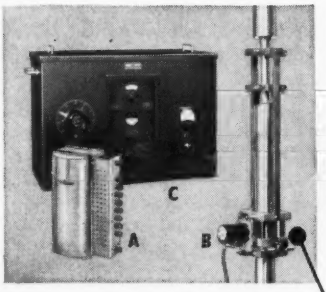
At the Ottawa Aeronautical Society's annual meeting on April 30, the following officers were elected: Chairman, Group Captain H. R. Foottit, RCAF; and Secretary-Treasurer, Squadron Leader D. C. Wilson, RCAF. J. Lukasiewicz was chosen to represent the IAS members, while Group Captain C. W. Crossland, RCAF, and R. N. Redmayne were selected to represent the membership of the EIC and the affiliates, respectively.

San Diego Section

Earl R. Hinz
Corresponding Secretary

The recently revived technical sessions of the San Diego Section are gaining

Increase the use of your Baldwin Testing machines with these accessories



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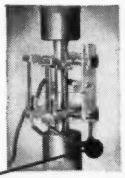
Includes *electric furnace* (A), *high temperature extensometer* (B), and *temperature controller* (C) which enable you to test metals at high temperatures. Various models are available for temperatures up to and including 2200° F.

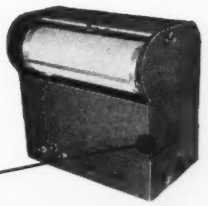
Extension Under Load Indicator

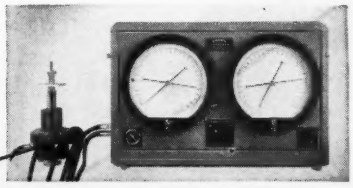
Used with a microformer type extensometer, this indicator will give you both a visual and audible signal at any desired predetermined amount of extension under load (such as 5% of the gage length).

SR-4 Extensometer and Strain Gage Recorder

This records on a chart a load-elongation graph for determining the elastic and plastic properties of materials. Various types are available.

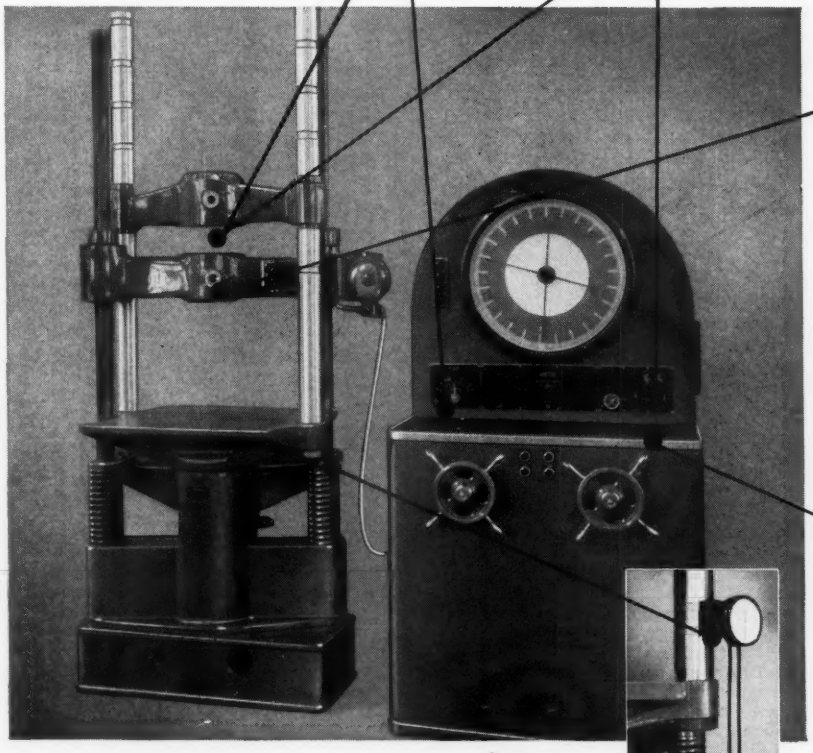


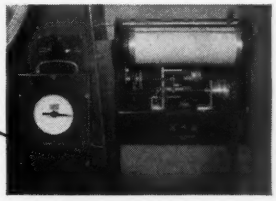




Air Cell (with Bourdon tube-type indicators)

Inserted in the grip slot and arranged to work with the testing machine indicator or a portable indicator, the Air Cell extends the precision ranges down to one pound full scale on any machine. This permits testing of light materials such as plastics, textiles, wood, foils, fibers, etc. with machines intended for higher capacities. (Bulletin 264.)





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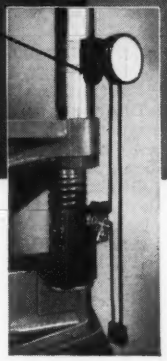
This controls ram speed at desired rate (8 pacing speeds, from 0.01 to 1.0 inch per minute). Enables you to meet test specifications. High magnification types for infinitely variable speeds from 0.002 to 4.0 inches per minute also available.



BULLETIN 261-A, a 12 page booklet, illustrates and describes fully Baldwin's line of grips, accessories and auxiliary equipment. Write Dept. 2301, Baldwin-Lima-Hamilton Corporation, Philadelphia 42, Pennsylvania.

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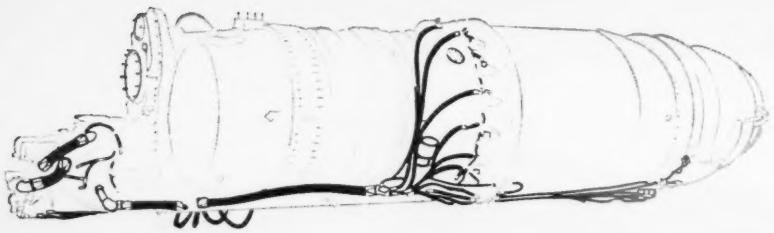
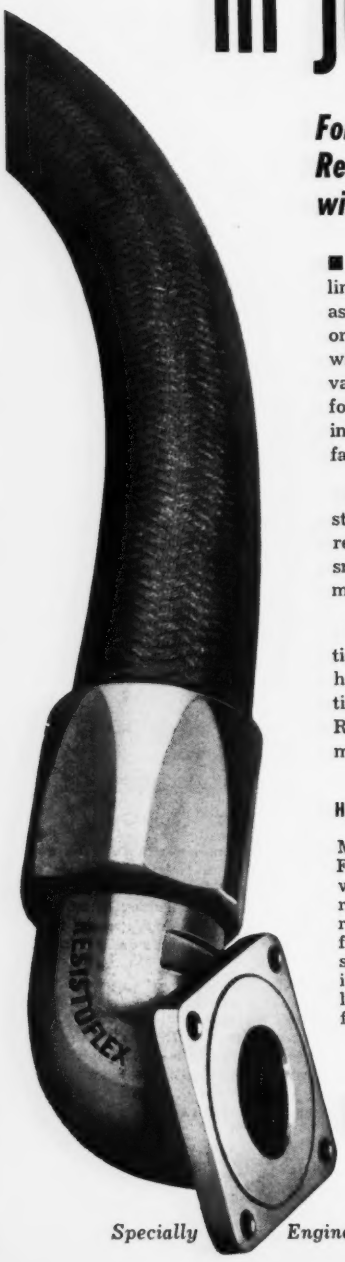


fits close quarters in jet engines



For best space factor, "plumb" with Resistoflex Hose Assemblies fitted with integral aluminum elbows

■ Jet engines have little space to spare for hose lines. For these close quarters, Resistoflex hose assemblies with integral elbows seem made to order. Fittings are compact, close-coupled — yet with ample wrench clearance. Available in a variety of useful angles, they also eliminate need for combinations of swivel nut assemblies with individual adapters. This not only improves space factors further, but also eliminates extra parts.

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Extra tough to start with, and in mass production for over 4 years, these Resistoflex fittings have had 100% trouble-free service. Flanged fittings are USAF and BuAER approved. Send for Resistoflex Aircraft Products Catalog — it gives more data.

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increasing popularity, as the attendance at the two July sessions indicated. Both meetings were held in the IAS Building, and the question-and-answer periods following the talks were accompanied by coffee and donuts served in the dining room. These added refreshments have tended to stimulate the informal discussions following the talks and thereby greatly increased the value of the meetings.

▶ The first technical session of the month was held July 9, with Rod Streed as Technical Chairman. The speaker was Dr. Hans Friedrich, a Design Specialist at Consolidated Vultee Aircraft Corporation, who discussed the development and principles of the "V-2 Control System." Dr. Friedrich was the leader of the group that developed the V-2 control system during World War II; so he was well qualified to present this talk.

Although the V-2 is now considered an "old" design, its means of control is still useful. Combined rocket-jet vanes and the more conventional ailerons produced the controlling moments for stabilized flight. The attitude-sensing device was a conventional type of gyro, because rate gyros were still in the undeveloped stage. A double-lead electrical network was then used to interpret the plain gyro signal that in turn was converted to an a.c. voltage by a ring modulator for amplification. The end control movement was then affected through hydraulic motors.

Dr. Friedrich explained his reason for basing the evening's talk on the dated V-2. Security is usually a matter of time, and unclassified subjects are limited to the older developments or futuristic thinking. In the case of the older developments, results have been obtained, and performance can be evaluated.

▶ The second technical session of the month was held July 23, with Dick White as Technical Chairman. The speaker, Seth Gunthorp, Research Test Engineer at Convair, presented a talk on "Structural Adhesives in Aircraft."

Mr. Gunthorp confined his discussion to the design of "glued" joints, a subject of more direct importance to designers than the make-up of the many adhesives available. The fundamental advantage of adhesive joining of metals is found in the fact that loads are carried over much larger areas without increasing joint size.

A basic criterion in glued-joint design is the avoidance of sharp discontinuities at the edges of mating sheets. In simple lapped joints, concentrated bending occurs at these edges, putting the adhesive under high tensile load. The optimum method of avoiding concentrated loads would be to use scarfed edges on the mating sheets. Because

EEMCo

technical bulletin

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of the impracticability of scarfing operations, an alternate method of stepped edges using a thin filler plate reduces the magnitude of the discontinuous load concentrations to an acceptable level. These filler or stiffener plates are about one-quarter the thickness of the parent material.

An interesting technique in producing honeycomb structures was described by the speaker. A fiber glass cloth impregnated with the adhesive is sandwiched between the outer plates and the honeycomb core. This cloth serves to effect a better distribution of the adhesive between mating parts and to produce more reliable and stronger joints.

San Francisco Section

E. A. Quarterman, *Secretary*

A meeting was held jointly with the Northern California Section of the American Rocket Society at Ramor Oaks, Atherton, Calif., on June 18. H. Julian Allen, Chairman of the IAS San Francisco Section, presided and introduced the ARS members. Thirty-five persons attended the dinner, and 40 more joined the group later.

William W. Kellogg, of Boeing Airplane Company, was the guest speaker and spoke on the topic, "Possibilities of Space Travel." Mr. Kellogg's address is summarized as follows:

The feasibility of a lunar trip still depends upon fundamental principles that have not been altered. Man has evolved with a body fitted for life at the bottom of the earth's atmosphere.

Basic data do not exist to make the extrapolation to outer space, even to specify the environment much above the surface of the earth. Before engineering techniques may be applied, data are required about the primary cosmic radiation and meteorite spectral distributions. These data are most easily obtained with a small unmanned satellite vehicle in a 200–300-mile orbit, which vehicle is within the realm of current technology. If favorable data are obtained, it is possible to proceed with engineering preparations for the circumlunar voyage; if not, the facts should be faced.

Currently, only the V-2, or A-4, rocket, along with the experiments and plans for utilizing it, is available to review the technical problems and analyze progress of rocket flight. Nuclear energy used thermodynamically to provide its own propellant mass is not practical. Basic problems of heat rejection for nuclear heat sources have to be faced. Any efficiency of achieving escape velocity by use of a satellite orbiting vehicle is overshadowed by the magnitude of the engineering problems without the orbital refueling.

Members Elected

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the REVIEW.

Elected to Associate Fellow Grade

Amstutz, Eduard, M.E., President, Swiss Federal Lab. & Vice-Chairman, Bd. of Directors "Swissair."

Transferred to Associate Fellow Grade

Heald, Ervin R., B.S. in Ae.E., Design Specialist, Douglas Aircraft Co., Inc. (El Segundo).

Lowell, Arthur L., M.S., Ch. of Aerodynamics, Missile Engrg. Div., McDonnell Aircraft Corp.

Staros, Basil, Ae.E., Sr. Proj. Engr., Sperry Gyroscope Co. Div., The Sperry Corp.

Elected to MEMBER Grade

Ames, Robert S., M.E., Mgr., Canopy & Laminate Departments, Goodyear Aircraft Corp.

Anker, Carl L., B.S.C.E., Engr. "A," Stress, Hayes Aircraft Corp.

Buitron, Gilbert, B.S.Ae.E., Product Test Engr., Ford Aircraft Engine Div. (Chicago).

Dietiker, Gilbert, Grad. in Aer. Eng., Engr., Canadair, Ltd.

Drougge, Georg, Dr.Ph., Head, Supersonic Div. & Wind Tunnels & First Research Engr., The Aeronautical Research Institute of Sweden.

Hatt, Fenwick G., Jr., B.S.Ch.E., Test Engr. "A," Ordnance Aerophysics Lab. (Texas).

Herwald, Seymour W., Ph.D., Engrg. Mgr., Air Arm Div., Westinghouse Electric Corp. (Friendship Airport).

Hingeley, James M., B.S. Industrial Engrg., Ch. Specifications Engr., Fairchild Aircraft Div., Fairchild Engine & Airplane Corp. (Hagerstown).

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Kirk, Donald R., B.S. in M.E., Sr. Design Group Engr., Consolidated Vultee Aircraft Corp. (Ft. Worth).

Kolb, Otto J., Mech. Engrg. Section Head, General Precision Labs.

Lazur, John W., B.E.E., Liaison Engr., Ford Instrument Co.

Lieske, George, B.E.E., Engr. Proj. Supvr., Ford Instrument Co.

McCafferty, Richard J., B.S., Research Scientist, NACA (Cleveland).

McKay, Gordon B., Ph.D., Asst. Prof., Mech. Engrg. Dept., Columbia Univ.

McKenney, Henry F., E.E., Ch. Engr., Ford Instrument Co.

Mordellet, Roger L. (Eng. Dipl.), Stress Engr., Canadair, Ltd.

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Myers, Joseph C., B.E., Exec., Panel on Aircraft Armament, Office of the Secretary of Defense, R&D Bd., Committee on Aeronautics.

Pollak, Richard J., M.S.Ae.E., Research Lab. Analyst "A," Northrop Aircraft Inc.

Rogers, Robert M., Electronic Engr. Directorate of Flight & All-Weather Testing, WADC, Wright-Patterson AFB.

Romberg, Lars G., Civ. Ing., Tech. Asst. to President, Scandinavian Airlines System.

Schroeder, George F., M.S. in E.E., Asst. Ch. Engr., Ford Instrument Co.

Scutt, John M., E.E., Liaison Engr., Ford Instrument Co.

Seliger, Victor H., M.E.E., Proj. Supvr., Ford Instrument Co.

Teubner, Harold C., M.S. in Ae.E., Lt. Col., USAF; Asst. Prof., Air Force Institute of Technology (Wright-Patterson AFB).

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Weber, William F., B.E.E., Proj. Supvr., Ford Instrument Co.

Wilson, Dan C., B.Sc. in C.E., Sr. Struct. Engr., Consolidated Vultee Aircraft Corp. (Ft. Worth).

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de Hart, W. G., S.B.Ae.E.

Fitch, Walter M., Research Analyst Engr., Boeing Airplane Co. (Wichita).

Froehlich, Jack E., Ph.D., in Aero., Ch., Guided Missile Engrg. Div., Jet Propulsion Lab., California Institute of Technology.

Hill, John H., B.A.Sc., Combustion Systems Engr., Gas Turbine Engrg. Div., A. V. Roe Canada, Ltd.

Hodgson, R. W., Bachelor's Degree in Mathematics, Dir., Research & Devel., Opto-Engineering Co.

Laskowitz, Isidor B., M.E., Cons. Engr., I. B. Laskowitz.

Louis, Harry, B.Sc. (Math. & Physics), Engrg. Supt., Fleet Mfg., Ltd.

Marsh, Billy Wayne, M.Sc. in Ae.E., Proj. Aerophysicist, Marquardt Aircraft Co.

Penry, Charles W., B. of Aero., Flight Test Liaison Field Engr., Chance Vought Aircraft Div., United Aircraft Corp. (Dallas).

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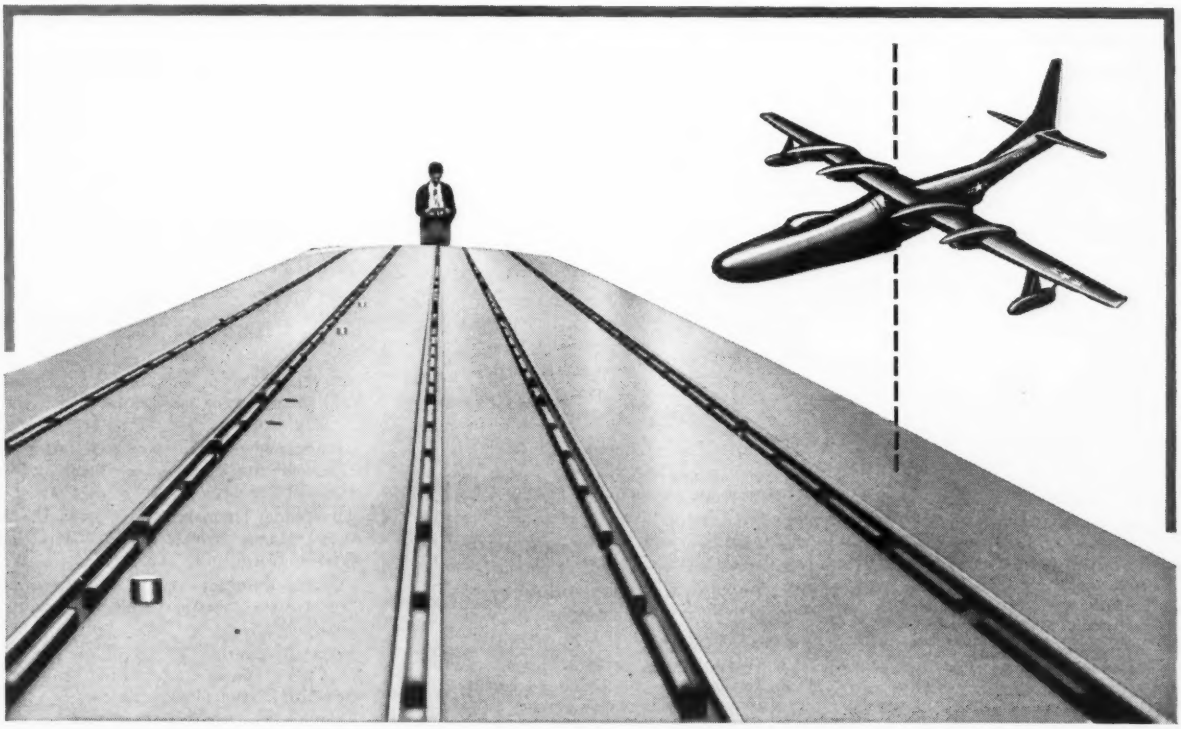

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Elected to Associate Member Grade

McGregor, John C., S.J.D., Partner, McGregor, Johnson & Malone; President, Nassau Research & Devel. Associates; V.-P. & Secretary, Kama Instrument Corp.

Morley, Edwin W., Optical Tooling Specialist, Canadair, Ltd.

Rhind, Hugh, Group Leader—Engineering, Canadair, Ltd.

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Elected to Technical Member Grade

Benson, Carl, Engr. Draftsman "A," North American Aviation, Inc. (Downey).

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Carta, Franklin O., S.M., Research Engr.—Aeroelasticity, United Aircraft Corp.

Conrad, Charles, Jr., B.S.E. in Ae.E., Ens., USN; Officer Student Pilot Training, Naval Air Station (Pensacola).

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Curran, Donald C., A.E., Lt. & Naval Aviator, USN.

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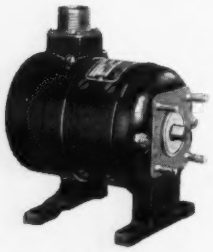

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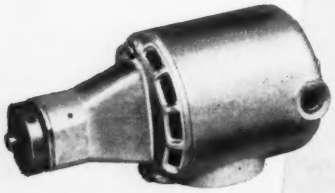

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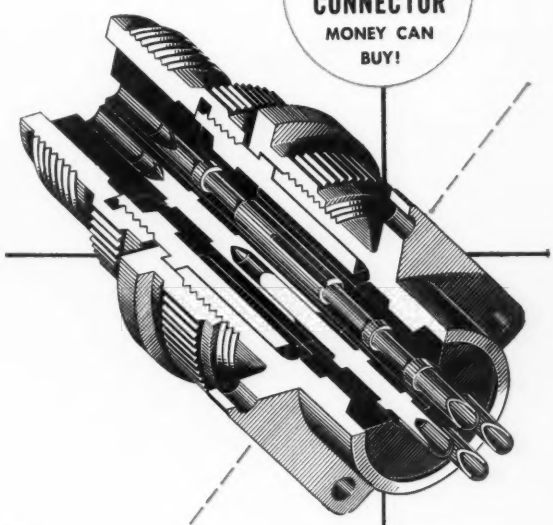

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Uram, Earl M., M.S., Research in Aerodynamics & Combustion, Harvard Univ.

Vretakis, Nicholas G., B.Aero.E., Test Engr., Wright Aero. Div., Curtiss-Wright Corp.

Weasner, William E., B.S. (Aero.).

West, Donald E., M.S., Aerodynamicist "B," Boeing Airplane Co. (Seattle).

White, Thomas J., B.A., Engr., Aerodynamics Sect., Chance Vought Aircraft Div., United Aircraft Corp.

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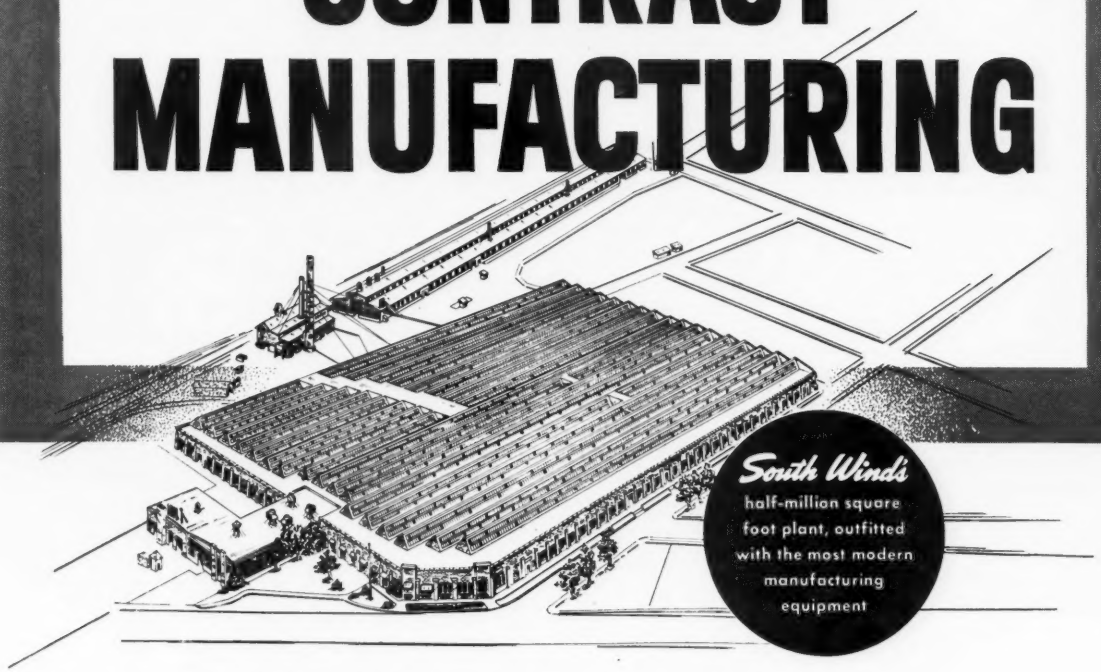

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Boundary Layer and Thermoaerodynamics

Boundary-Layer Control and Supercirculation. John S. Attinello. *Aero. Eng. Rev.*, Sept., 1953, p. 24. 11 refs. Relation to wing-lifting effectiveness and potentialities of jet-powered air pumping systems.

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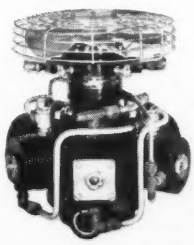

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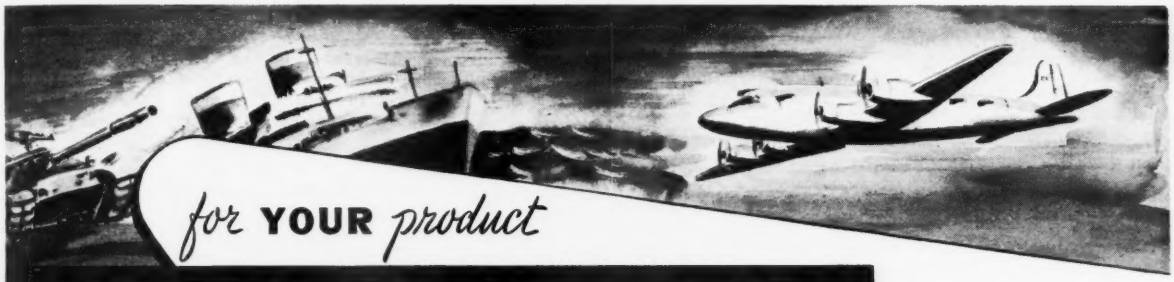

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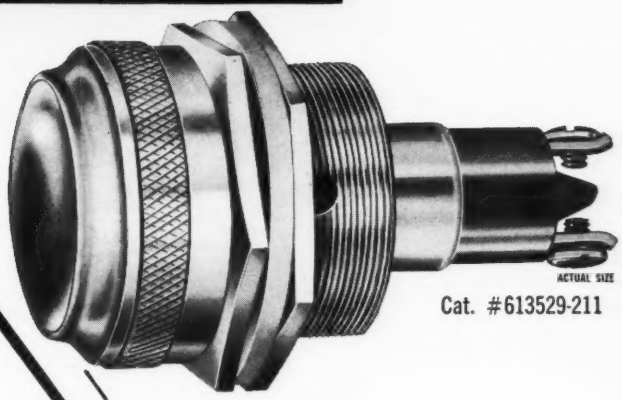

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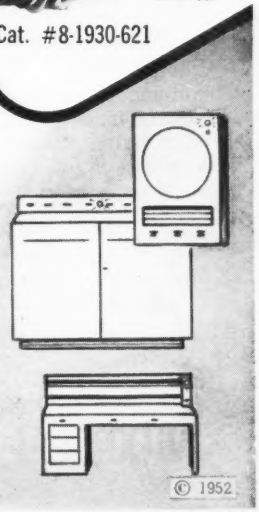

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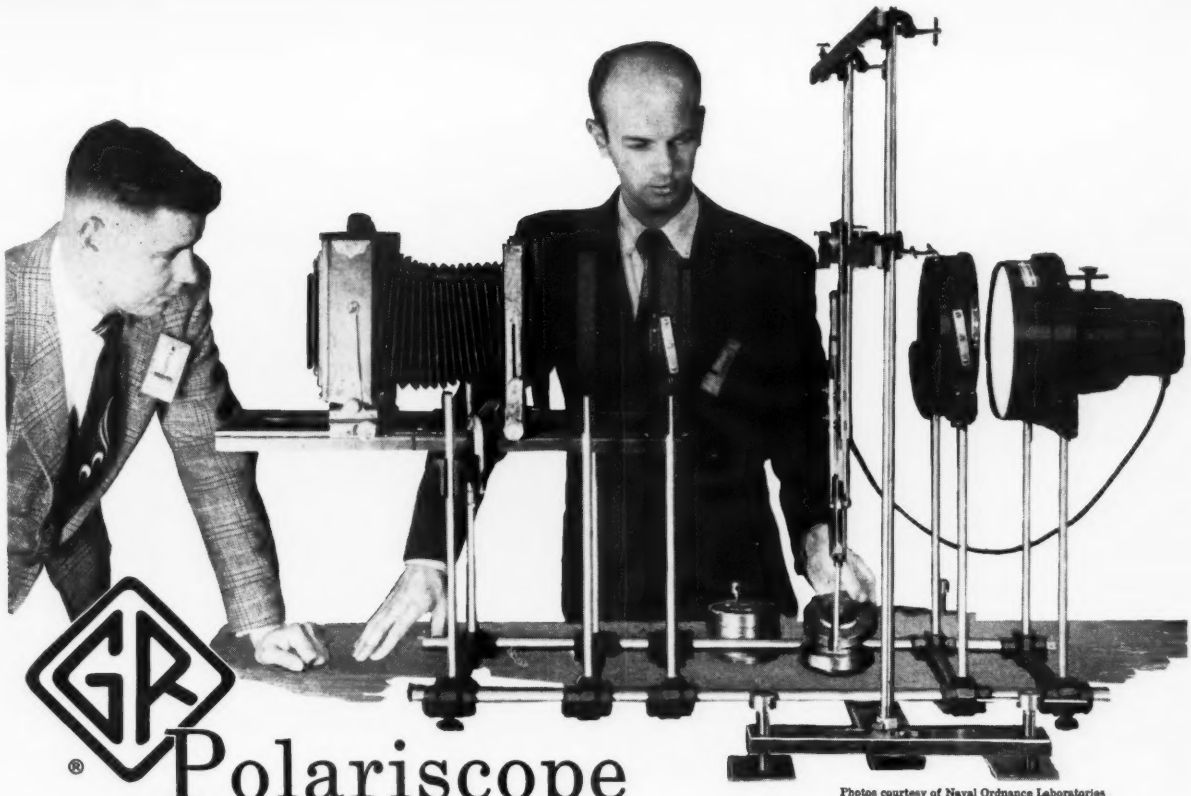

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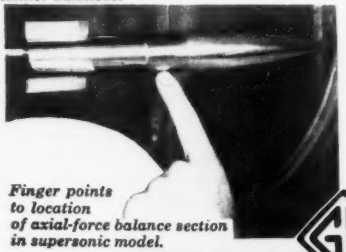

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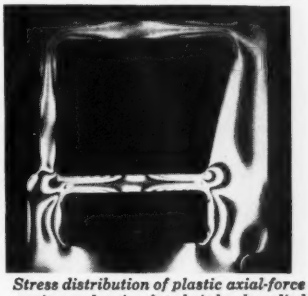

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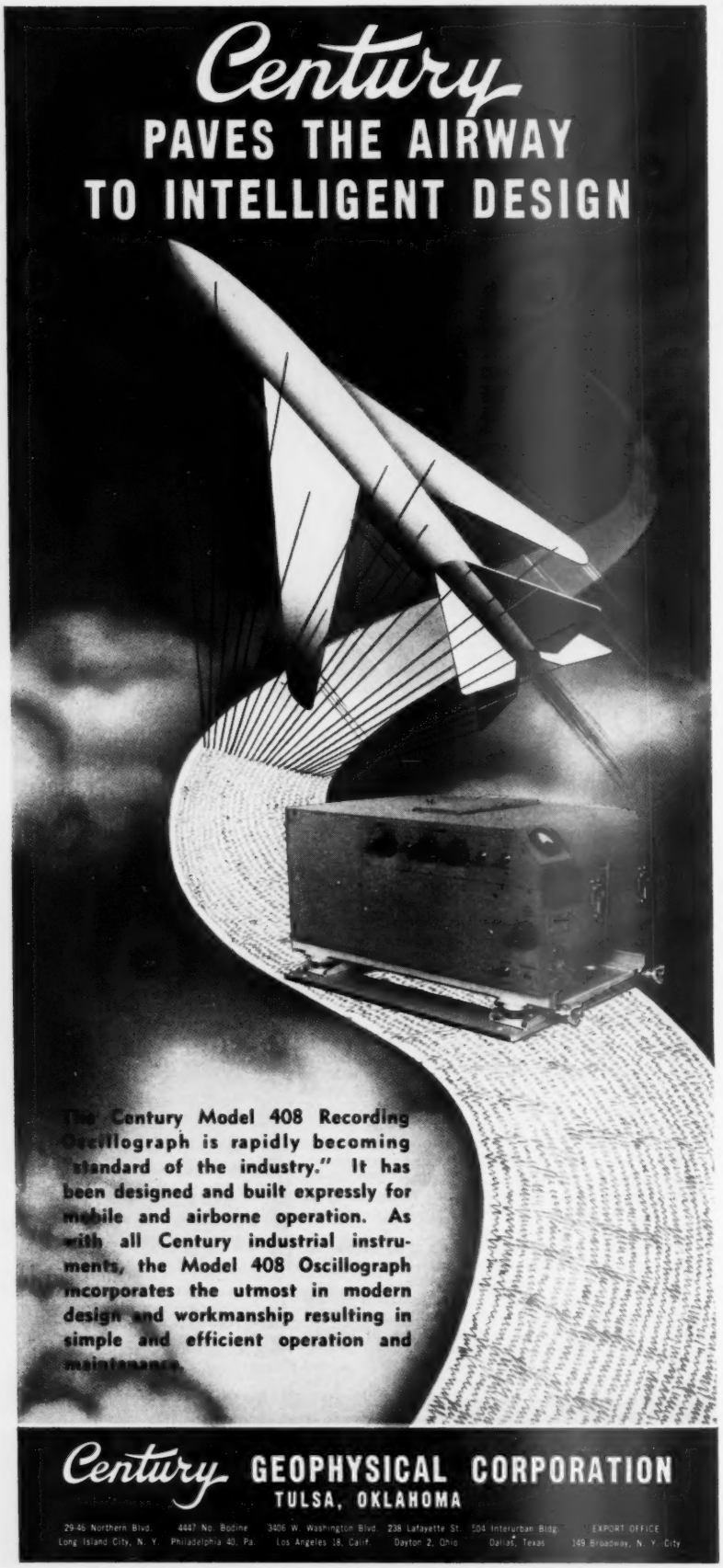
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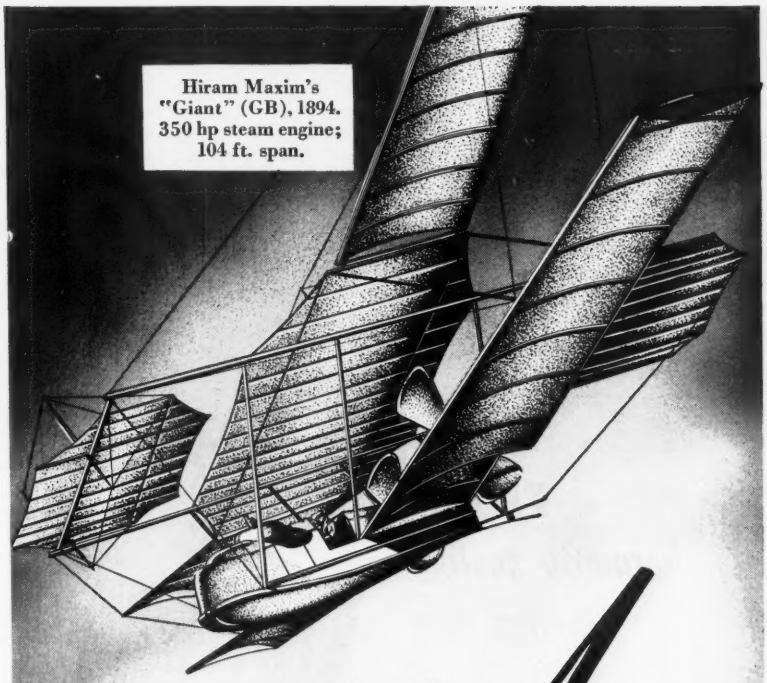

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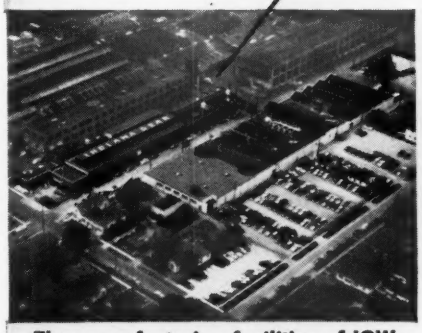

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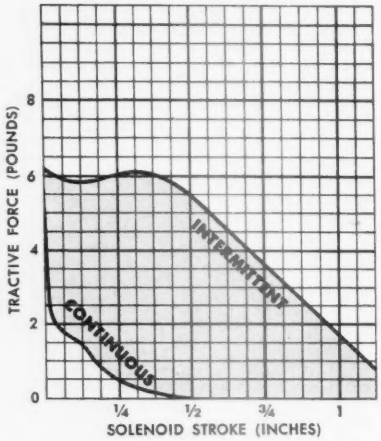

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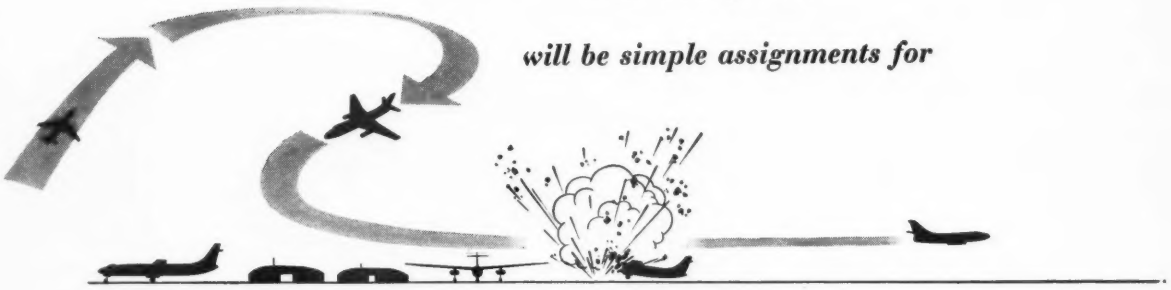

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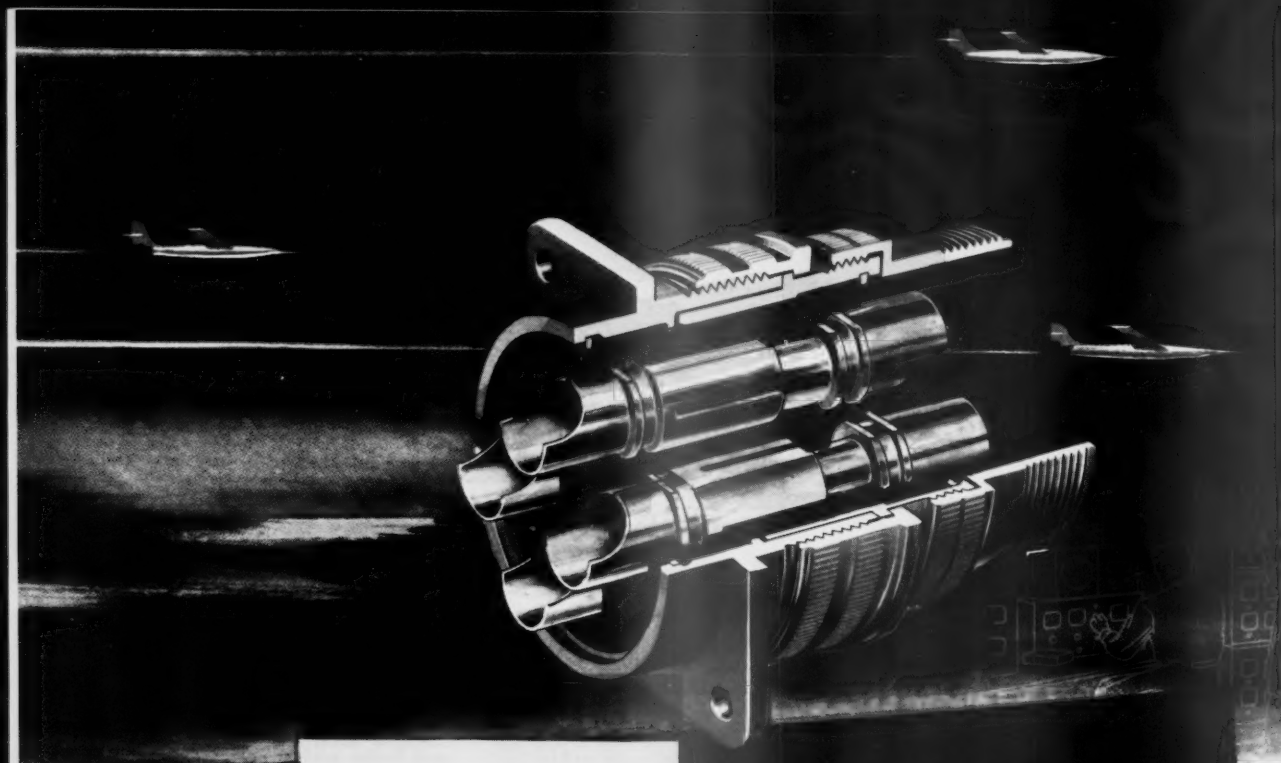

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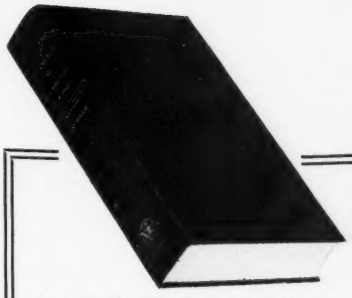

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DOW CORNING

Silicone News

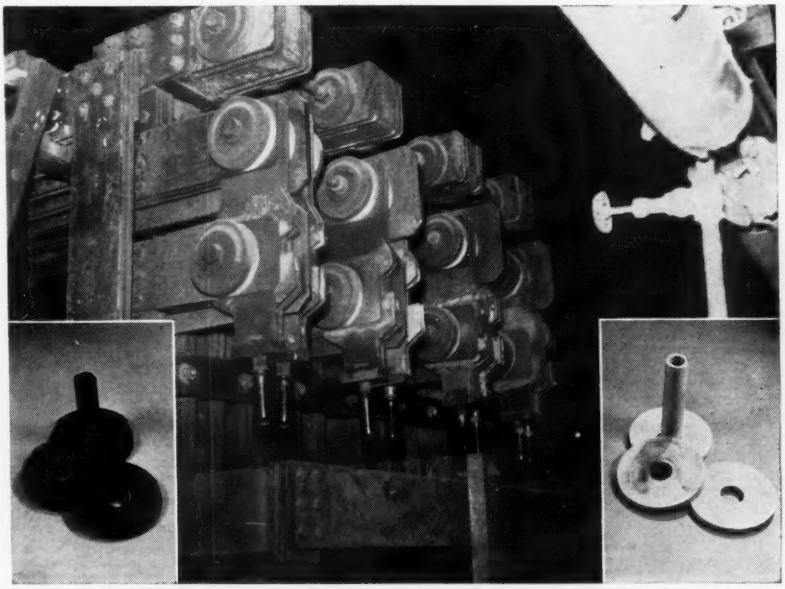
Vol. 1, Number 2 • PUBLISHED BY DOW CORNING CORPORATION, MIDLAND, MICHIGAN

Modified Silicone Finish Used On Vehicle Heaters For Its Superior Heat And Salt Spray Resistance

Heaters manufactured for use in Ordnance vehicles by the Southwind Division of Stewart-Warner Corporation must withstand temperatures far higher than those involved in civilian applications. In the process of selecting the best finish for these units, the relative heat and corrosion resistance of organic and modified silicone paints were severely tested. The photograph shows the results.

The heater shell at left was sprayed with a modified silicone paint which is formulated by Midland Industrial Finishes, and baked for 30 minutes at 400 F. A similar unit, at right, was sprayed with conventional olive drab (TT-E-485b), and baked for 45 minutes at 250 F. Panels in the foreground illustrate the appearance of both finishes before testing.

Both shells were held at 500 F for 4 hours. The conventional finish was then exposed to salt spray for 100 hours. The modified silicone finish was similarly exposed to a salt spray for 300 hours or three times as long. The organic finish was stained, faded, and badly disintegrated, while the silicone coating remained virtually unchanged. As a result, Stewart Warner specified the modified silicone finish for all such heaters. *No. 11*



Silicone Switch Spacers Serviceable After 30 Months; Organic Spacers Lasted Less Than 1 Month

Thirty days was the maximum service life obtainable with cotton-phenolic spacer disks and tubes used to insulate the knife switches on a 45,000 ampere graphitizing transformer.

The organic insulators shown in the left insert were removed after less than 30 days. Operating temperatures ranging from 400 to 500 F converted them to charred, cracked, shrunken conductors. Constant shrinkage required daily tightening of switches; kept maintenance costs up. Replacement meant loss of an entire day's production.

The silicone-glass spacer disks and tubes shown at right were examined during a routine shutdown after 11 months' service. They were in excellent condition and the switches had never required tightening. At that time the silicone-glass laminates had already repaid many times their original cost by increasing production, reducing maintenance costs and down time.

Again, after 30 months of service these silicone-glass laminates were inspected and found to be in very good condition. Insulation value was still high and switch tightening had been virtually eliminated.

Electrical insulating materials coated, impregnated or bonded with Dow Corning silicone varnishes and resins give electrical engineers unprecedented freedom in design; save copper; permit substantial reduction in size and weight of electric machines. They give maximum overload protection; provide maximum life and reliability in spite of overloads, high ambients and humid or corrosive atmospheres; substantially eliminate fire hazard caused by failure of conventional insulation. (*continued pg. 2*)

Silastic* Die-Tips Give Long Service In Hot-Stamping Plastic Ornaments

Mass production of the multi-colored ornaments common to even the least expensive automobiles, is accomplished by hot-stamping pigmented foil to the molded plastic parts.

A problem in developing the process was to find a resilient die-tip material. Mass production techniques required that the material should not stick to the foil at surface temperatures in the range of 500 F, and remain resilient after thousands of impressions at such elevated temperatures. After trying many materials, the problem was solved with Silastic by the Bay Manufacturing Division, Electric Auto-Lite Co. The same Silastic tips have been in use for more than 3 years, and none of them has worn out, lost its flexibility or peeled from its metal backup plate.

The heat stability and aBhesiveness characteristic of Silastic have proved to be equally useful in other similar applications. Silastic-coated pressure plates, backing bars or press pads are used in printing or sealing plastic packaging materials. Silastic rings are used on banding machines to press gold leaf ribbon on cosmetic containers. Silastic-covered rolls are used in the hot or cold dip coating of fabrics, plastic film and metal sheeting or foil. *No. 12*

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DOW CORNING Silicone News

NEW DEVELOPMENT AND TECHNICAL DATA

For copies of any of the publications reviewed in this column or for data relating to any of the articles printed in this issue of the Dow Corning Silicone News, simply circle the corresponding reference number on the coupon below.

"Tall Tales and Fabulous Facts" is a new 24-page booklet in which a parallel is drawn between the tall tales our ancestors told about such legendary characters as Paul Bunyan, Davy Crockett and Pecos Bill and some of the equally fabulous facts about Dow Corning silicone products. *No. 15*

•

Use of bare magnet wire coated with new Dow Corning 1360 Wire Enamel permits operation of small electric machines and electronic parts at 180 C. Flexibility, scrape hardness and dielectric strength compare favorably with those of the best organic wire enamels. Life expectancy at 180 C is in the range of 50,000 hours compared with 200 hours for wire insulated with conventional enamels. *No. 16*

•

Pharmaceutical properties of Dow Corning 200 Fluids are described in a recent reprint from the Journal of American Pharmaceutical Association. This article includes a study of compatibilities with acids, alcohols, waxes and commercial ointment bases. *No. 17*

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"Silicones Help Convair B-36 Fight Cold." This reprint of an article from Aviation Week describes and illustrates various nonrestricted applications for Silastic and other Dow Corning Silicones in one of the largest aircraft, operating at temperatures ranging from —100 to +500 F. *No. 18*

•

Current Aeronautical Material Specifications and SAE-ASTM Specifications for silicone rubber are outlined in a data sheet which also lists the Silastic stocks which meet these specifications. Handy reference for any design engineer working on military projects. *No. 19*

•

Now available, the new 1953-54 Reference Guide to Dow Corning Silicone Products summarizes properties and briefly describes applications for commercially available silicones. Indexed for easy reference. A "must" in every designer's catalog file. *No. 20*

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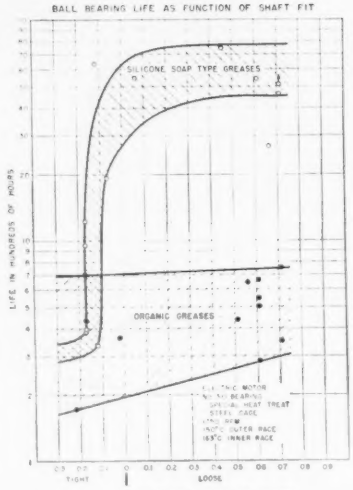
New Antifoam A Spray bomb instantly defoams many of the most violent and persistant foamers. Spray consists of Dow Corning Antifoam A combined with Freon propellent and is effective in concentrations as low as 0.1 to 1 ppm. Now available from laboratory supply houses. *No. 21*

Bearings Fitted To Compensate For Thermal Expansion Further Extend Service Life of Silicone Grease

In electric motors which may operate hot, the mechanical fit-up of the bearing assembly has a critical effect on the life expectancy of silicone grease. This was proved by the life-testing of various greases in the bearings of totally enclosed nonventilated induction motors operating at high temperatures. The relation between shaft-fit and life in hours is shown in Figure 1.

FIGURE 1
BALL BEARING LIFE AS FUNCTION OF SHAFT FIT



In the TENV induction motors used to test bearing life at 150 C, these curves indicate that the life of Dow Corning 44 lubricated bearings with a shaft-fit of 0.2 mils loose is about 15 times the life of identical bearings with a shaft-fit of 0.2 mils tight.

These data show the importance of mechanical fit-up. A tight shaft-fit, for example, may take up most of the radial clearance in the bearing. Where the inner race operates at a higher temperature than the outer race, unequal thermal expansion may put the balls under compression. Any combination of mechanical fits which produces radial clearances inadequate at operating temperatures, or poor bearing alignment, will subject the grease to extreme pressures and result in unsatisfactory bearing life.

The test data also showed that an end play of at least nine thousandths of an inch was effective in extending the service life of silicone grease lubricated bearings.

The subject of Design Considerations for Optimum Performance of Silicone Greases in Ball Bearings is more fully developed in a paper read before the ASLE. *No. 14*

KNIFE SWITCH SPACERS *continued*

These advantages were inherent in the first silicone resins and varnishes introduced over ten years ago by Dow Corning Corporation. Since that time many improvements have been made and new silicone dielectrics are constantly being introduced by our research chemists and product engineers.

For example, Dow Corning 2105 is a relatively new silicone product for making silicone-glass laminates that retain a dielectric strength of 180 volts per mil after 5000 hours at 250 C. That's approximately 100 times the dielectric life of the best laminates previously available. This new resin exhibits slight thermoplasticity at elevated temperatures, but not enough to limit its use in most applications where maintenance of dielectric strength is of importance.

The following table compares typical physical properties of silicone-glass laminates made from ESS 261, washed glass cloth, bonded with Dow Corning 2103 Resin and Dow Corning 2105 Resin. Operating conditions will determine which type of laminate is most suitable for specific applications. *No. 13*

Typical Properties	Laminates of ESS 261 Washed Cloth Bonded with 2103 Resin	2105 Resin
Thickness	⅛"	⅛"
Flexural Strength, psi		
at 77 F	26,500	24,500
at 500 F	10,100	4,200
at 500 F, after aging 100 hr at 500 F	6,400	2,500
Bond Strength, pounds	1,050	1,000
Water Absorption[1], percent	0.150	0.05
Dielectric Strength, volts per mil ¼" electrodes	85	250
Dielectric Constant[2] at 25 C		
at 10^2 cycles		3.62
at 10^6 cycles	3.88	3.40
Power Factor[2] at 25 C		
at 10^2 cycles		0.0250
at 10^6 cycles	0.0120	0.0036
Arc Resistance	250	280

[1] After 24 hour immersion.
[2] Samples conditioned 24 hr at 25 C prior to testing.

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Jet & Turbine

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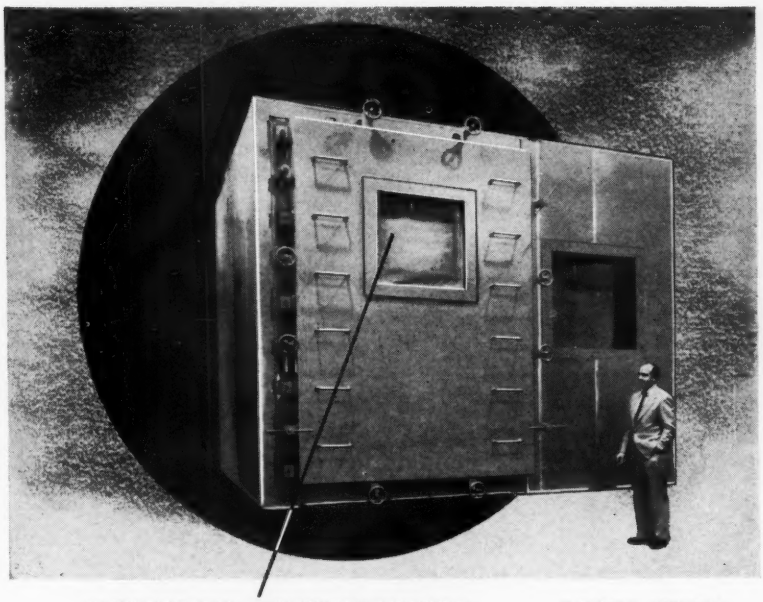

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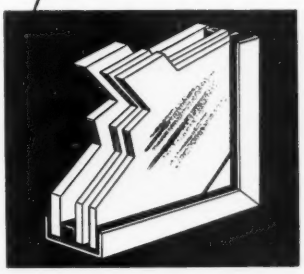

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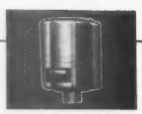

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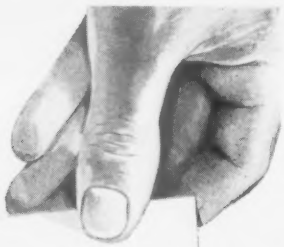

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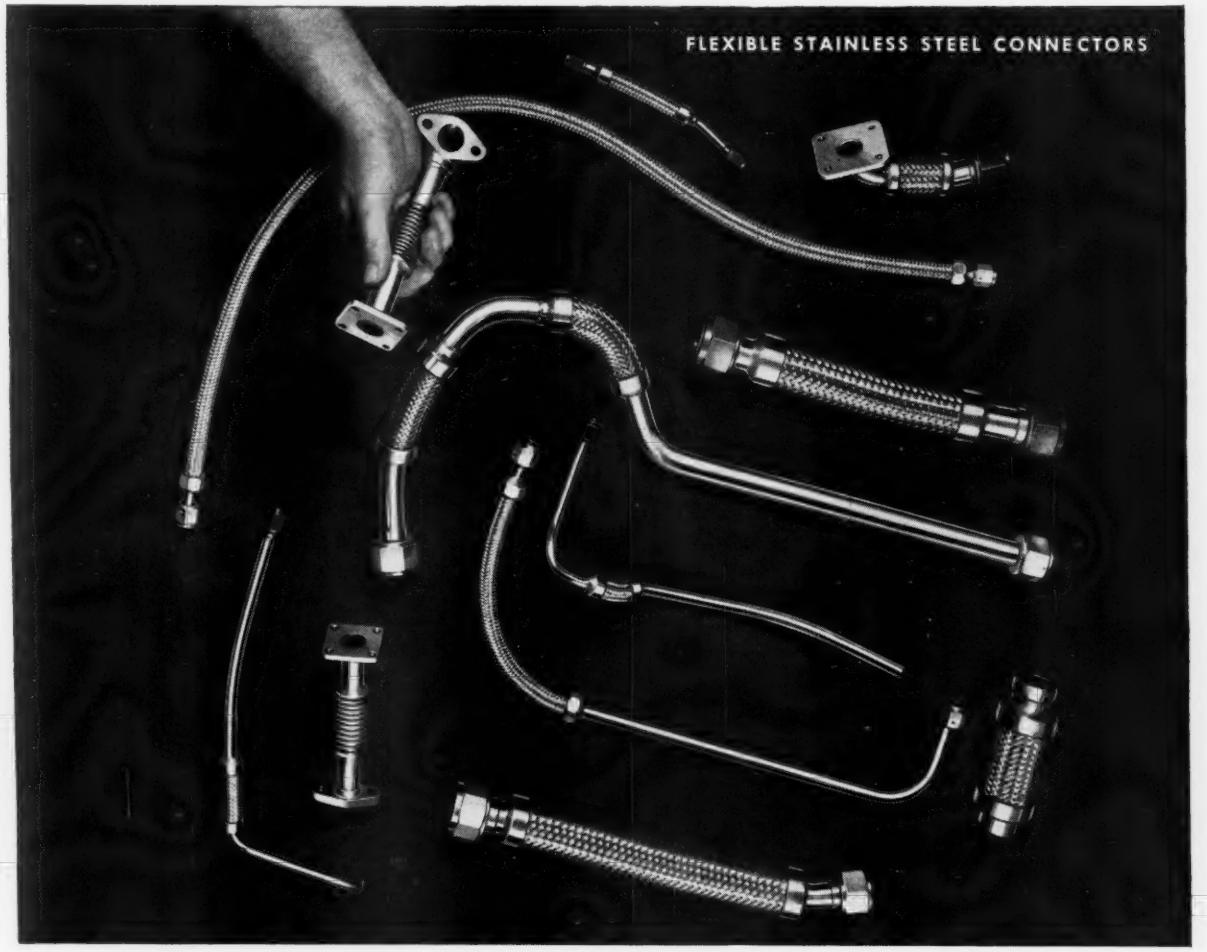

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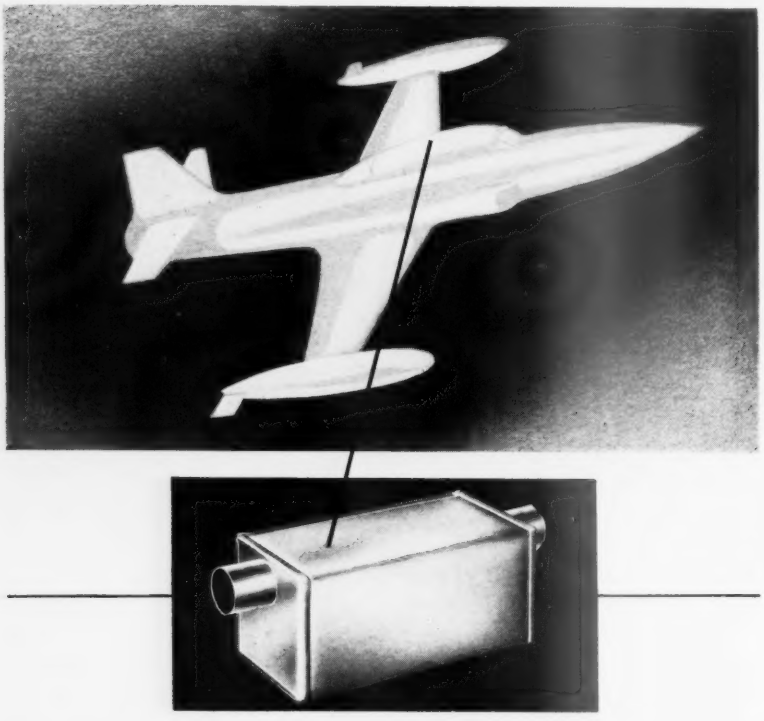

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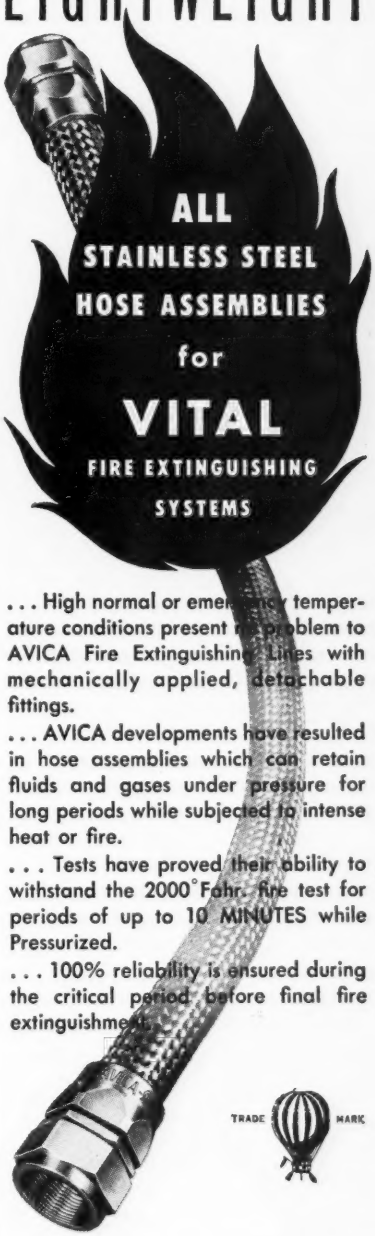

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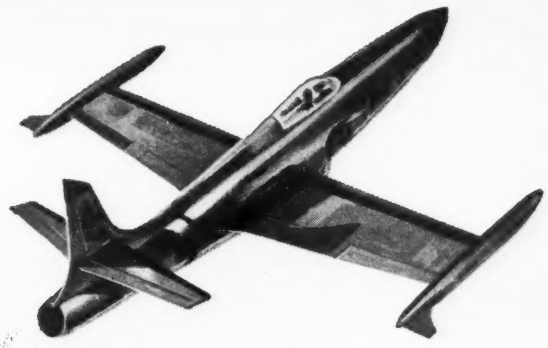

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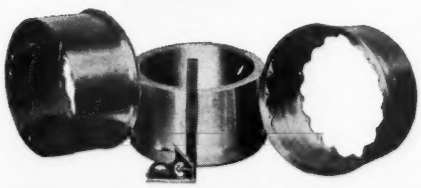

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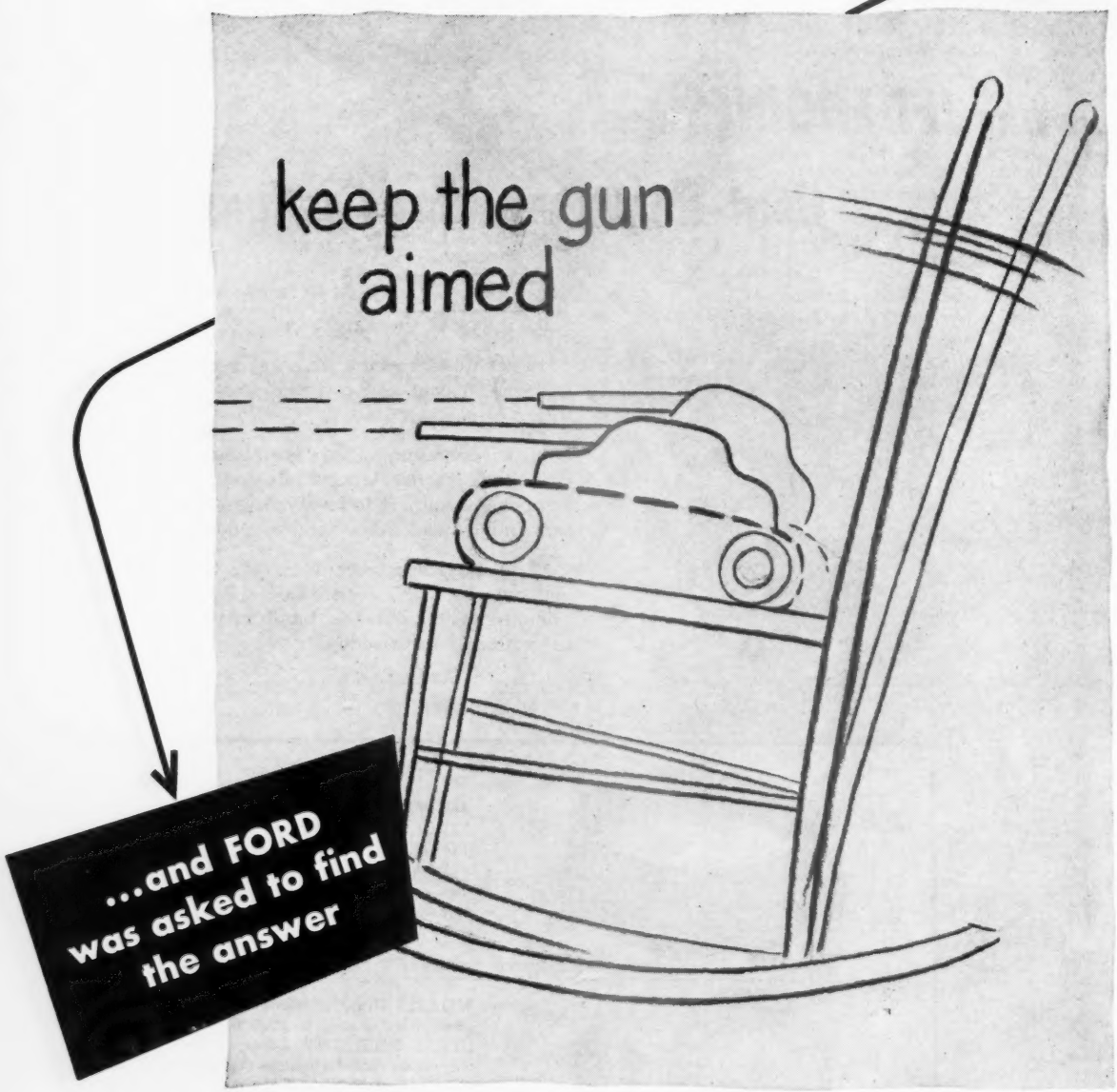

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Civil Air Regulations and Reference Guide for A & E Mechanics. Los Angeles, Aero Publishers, Inc., 1953. 120 pp., illus. $2.00.

This book combines in one volume all the Civil Air Regulations required and recommended by the CAA for A & E mechanics. It comprises a reference guide of questions and answers on CAR's which are similar to those asked by the CAA for A & E mechanics certificates and copies of inspection forms.

ELECTRONICS

Electronic Circuitry for Instruments and Equipment. Milton H. Aronson. Pittsburgh, Pa., Instruments Publishing Co., 1953. 310 pp., illus. $4.00.

This textbook, originally printed serially in *Instruments* under the title of "Instrument Electronics," is concerned with the basic electronic circuitry for instruments, communications, television, laboratory apparatus, and military equipment. The treatment is nonmathematical, and the book may be considered as a text for a home-study course. Over 450 multiple-choice questions are included. Contents: (1) The Electrical Nature of Matter. (2) Circuit Elements—Resistance, Capacitance, Inductance. (3) Impedance and Resonance. (4) Signals and Simple Circuits. (5) Vacuum Tubes. (6) Gas-Filled Tubes. (7) Rectification and Power Supplies. (8) Amplifier Circuits. (9) Solid-State Amplifiers. (10) Oscillator Circuits. (11) Signal-Shaping Circuits. (12) Electrical and Electronic Test Equipment. (13) R-F. Communication and Television. (14) Scientific and Industrial Instruments. (15) Military Electronics.

Transmitting Valves; The Use of Pentodes, Tetrodes and Triodes in Transmitter Circuits. J. P. Heyboer. Revised by P. Zijletra. (*Electronic Valves*, Vol. 7.) Eindhoven, Netherlands, Philips' Technical Library; Houston, Texas, Elsevier Press, Inc., 1951. 284 pp., illus. $7.50.

The main object of the author, J. P. Heyboer, who was a member of the scientific staff of Philips' Company, was to prepare a complete study of transmitting tubes and their applications, passing in turn to modulation, oscillation, and frequency multiplication. In each case there are derived the more important theoretical quantities for the characteristics of the tubes, partly by calculation and partly by graphic means. The present book is purposely limited to the treatment of tubes in which the transit time is of minor importance. Although intended for the advanced student and the professional engineer, the text is not overburdened with mathematics and is well illustrated by over 200 diagrams and charts.

Application of the Electronic Valve in Radio Receivers and Amplifiers. Volume 2, A.F. Amplification—The Output Stage-Power Supply. B. G. Dammers, J. Haantjes, J. Otte, and H. Van Suchtelen. (*Electronic Valves*, Vol. 5.) Eindhoven, Netherlands, Philips' Technical Library; Houston, Texas, Elsevier Press, Inc., 1951. 431 pp., illus. $9.00.

This second part of the trilogy on valve applications of electronic tubes deals with a.f. amplification, power amplification, and power supplies. The approach to the subject is both theoretical and practical. A large number of graphs and design calculations have been included to illustrate the performance of the various types of tubes in different circuits. A selected bibliography is given at the end of each chapter. The four authors are members of the scientific staff of the Philips Company.

FUELS AND LUBRICANTS

ASTM Manual on Measurement and Sampling of Petroleum and Petroleum Products. Gaging, Temperature Measurement, Volume Calculations and Corrections, Water and Sediment, Gravity, Sampling. 2nd Ed. Philadelphia, American Society for Testing Materials, 1953. 133 pp., illus. $1.50.

HISTORY

Palette de Souvenir, 1901–1952. Paris, Air France, 1953. 49 pp., illus.

An illustrated souvenir album covering 50 years of aviation history, with particular reference to French developments.

INSTRUMENTS

Measurement Techniques in Mechanical Engineering. R. J. Sweeney. New York, John Wiley & Sons, Inc., 1953. 309 pp., diagrs. $5.50.

The purpose of this book is to provide a source of information on the measurement techniques that are commonly used in performance testing of power equipment. In this field are included tests of engines, pumps, compressors, and combustion and heat-transfer apparatus. The mechanical quantities that may need to be measured include length, area, time, speed, force, pressure, temperature, and fluid flow rates. The more common applications of electrical and chemical methods in mechanical engineering are discussed. The discussion of instruments covers their primary function of measurement and indication and their function as signaling devices to automatic controllers. The intent has been to provide an insight into principles of use and design, and no attempt has been made to give detailed descriptions of current designs of instruments. Footnote references have been made to extended treatments of the subject.

Contents: (1) Introduction; (2) Mensuration; (3) Mass; (4) Time and Speed; (5) Electrical Measurements; (6) Dynamometers; (7) Pressure; (8) Temperature; (9) Fluid Flow; (10) Calorimetry; (11) Chemical Analysis; (12) Automatic Controls; Appendix; Thermoelectric Charts; Index.

For Information on IAS Library Service Facilities, see page 99

Statements and opinions expressed in Book Reviews are to be understood as individual expressions and not necessarily those of the Institute.

MATERIALS

Properties of Metallic Materials. A Symposium Organized by the Institute of Metals and Held at the Royal Institution, London, on 19 November 1952. (Monograph and Report Series No. 13.) London, Institute of Metals, 1953. 368 pp., illus. 35*s*. $5.50.

Contents: Paper 1396, Specialized Microscopical Techniques in Metallurgy, S. Tolansky. Paper 1397, Radioisotopes in the Study of Metal Surface Reactions in Solutions, Massoud T. Simnad. Paper 1398, The Influence of Machining and Grinding Methods on the Mechanical and Physical Condition of Metal Surfaces, Peter Spear, Ian R. Robinson, and K. J. B. Wolfe. Paper 1399, The Effect of Lubrication and Nature of Superficial Layer After Prolonged Periods of Running, F. T. Barwell. Paper 1400, The Crystalline Character of Abraded Surfaces, P. Gay and P. B. Hirsch. Paper 1401, The Effect of Surface Conditions on the Mechanical Properties of Metals, Mainly Single Crystals, E. N. da C. Andrade. Paper 1402, The Effect of Surface Condition on the Strength of Brittle Materials, C. Gurney. Paper 1403, The Influence of Surface Condition on the Fatigue Strength of Steel, R. J. Love. Paper 1404, The Influence of Surface Films on the Friction and Deformation of Surfaces, F. P. Bowden and D. Tabor. Paper 1405, Diffusion Coatings, D. M. Dovey, I. Jenkins, and K. C. Randall. Paper 1406, The Nature and Properties of the Anodic Film on Aluminium and Its Alloys, H. W. L. Phillips. Paper 1407, Chemical Behaviour as Influenced by Surface Condition, U. R. Evans. Paper 1408, The Effect of Method of Preparation on the High-Frequency Surface Resistance of Metals, R. G. Chambers and A. B. Pippard. General Discussion. Subject and Name Indexes.

Engineering Metallurgy. Bradley Stoughton, Allison Butts, and Ardrey M. Bounds. 4th Ed. New York, McGraw-Hill Book Company, Inc., 1953. 479 pp., illus. $7.50.

This edition is designed to be used by sophomore–junior engineering students, particularly those who do not plan to specialize in metallurgical engineering. Subject matter covered deals primarily with metal utilization rather than production. It covers structure, properties, treatment, and working of metals and alloys. Chapters on alloys, heat treatment, metals as materials of construction, and sizing and shaping have been

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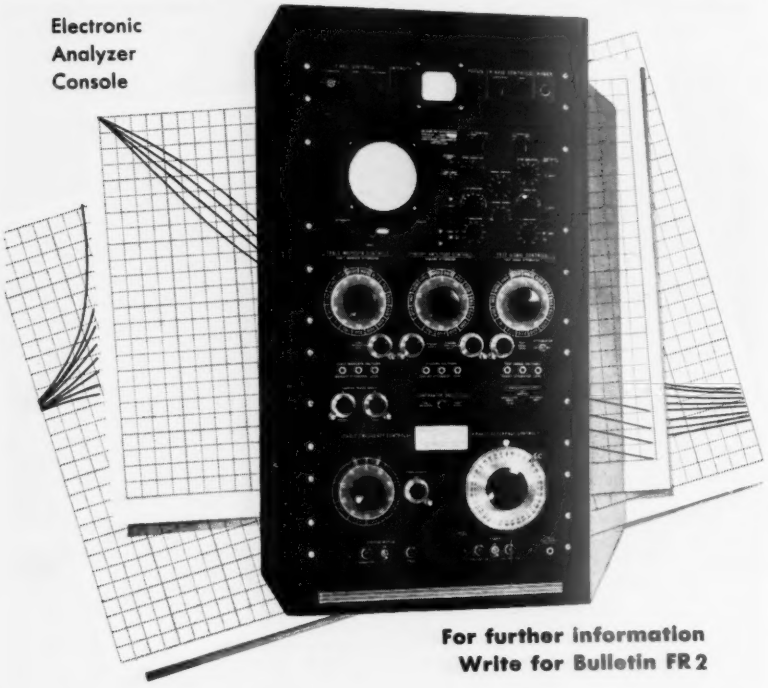

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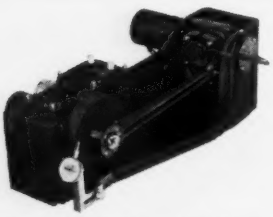

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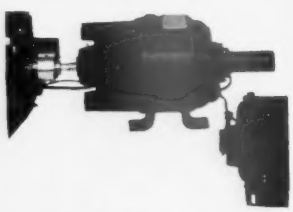

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largely rewritten to bring them up to date. New developments in metallurgy since the third edition, and especially since World War II, have been added. They include: metallurgy in atomic energy development, machining and machinability, plastics, new welding methods, new casting methods, new methods of testing such as acoustic and supersonic, new types of steel and cast iron, new nonferrous alloys, and time-temperature-transformation curves.

Textbook of the Materials of Engineering. Herbert F. Moore and Mark B. Moore. 8th Ed. New York, McGraw-Hill Book Company, Inc., 1953. 372 pp., illus. $6.00.

Presentation is made of the properties of various materials used for machine and structural parts which affect the strength, stiffness, ductility, and resistance to corrosion or wear. The coverage of these properties includes methods of production such as casting and molding and chemical and mechanical methods of strengthening materials, heat treating, alloying, hammering and rolling, and aging. The internal structures and processes producing various materials receive brief descriptions. Effectiveness of various treatments for structural or machine parts is demonstrated, along with the limiting stress, strain, or strain energy under which various metals function satisfactorily. This new edition includes recent information given by the electron microscope, a brief discussion of resistance to fatigue by metals under compressive loads, discussions of boron and titanium, and a new treatment on numerous plastics (with a tabulation of their physical properties). An added feature is the use of the nomenclature for fatigue of metals recommended by the ASTM. The text, distinctly elementary in character, is intended for draftsmen, inspectors, machinists, and others concerned with materials of engineering. Selected references for advanced reading, and questions, are included for the student.

1952 Book of ASTM Standards, Including Tentatives. Philadelphia, American Society for Testing Materials, 1953. 7 vols., illus., plates, diagrs.

Contents: Part 1, Ferrous Metals, 1,602 pp., $12. Part 2, Nonferrous Metals, 1,359 pp., $10. Part 3, Cement, Concrete, Ceramics, Thermal Insulation, Road Materials, Waterproofing, and Soils, 1,666 pp., $12. Part 4, Paint, Naval Stores, Wood, Fire Tests, Sandwich Constructions, Building Constructions, 1,182 pp., $10. Part 5, Fuels, Petroleum, Aromatic Hydrocarbons, and Engine Antifreezes, 1,282 pp., $10. Part 6, Rubber, Plastics, and Electrical Insulation, 1,520 pp., $12. Part 7, Textiles, Soap, Water, Paper, Adhesives, and Shipping Containers, 1,364 pp., $10. This *1952 Book of ASTM Standards* comprises more than 9,975 pages and includes more than 2,000 specifications tests, and definitions for materials. Each part of the 1952 book is complete with detailed subject index and two tables of contents and is arranged to provide as usable a book as possible for technologists and others in industry and government who must purchase materials or evaluate their quality through standard tests. The books are kept up to date with the issuance of annual supplements. A supplementary volume providing a complete index to the standards is being published late this year.

ASTM Standards on Plastics. Sponsored by ASTM Committee D-20 on Plastics: Specifications, Methods of Testing, Nomenclature, Definitions. March, 1953. Philadelphia, American Society for Testing Materials, 1953. 1,216 pp., illus. $5.25.

MATHEMATICS

Conformal Mapping. L. Bieberbach. New York, Chelsea Publishing Company, 1953. 234 pp., illus. $2.25.

This general text includes chapters on the foundations and linear functions, rational functions, general considerations, study of mappings represented by given formulas, and mappings of given regions. It is a translation of the fourth

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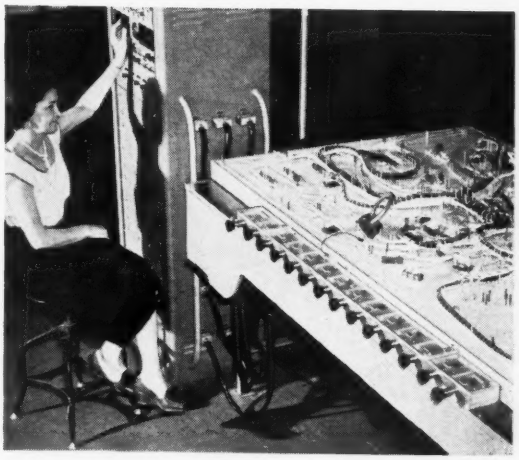

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edition (1949) of Bieberbach's *Einführung in die Konforme Abbildung*.

An Introduction to Linear Programming. Part 1, An Economic Introduction to Linear Programming, W. W. Cooper and A. Henderson. Part 2, Lectures on the Mathematical Theory of Linear Programming, A. Charnes. New York, John Wiley & Sons, Inc., 1953. 74 pp., illus. $2.50.

The lectures contained in this volume were originally developed as part of a research seminar supported in part by grants from the U.S. Air Force to the Carnegie Institute of Technology, to the School of Industrial Administration for research in intrafirm behavior and to the Department of Mathematics for research in applied mathematics. A bibliography of 29 references is appended to Part 1 as a guide to further reading.

Lectures on Analytic and Projective Geometry. Dirk J. Struik. Cambridge, Mass., Addison-Wesley Publishing Company, Inc., 1953. 291 pp., illus. $6.50.

The present book represents a one-term course, mainly for juniors and seniors, given at Massachusetts Institute of Technology. The texts start with affine and projective concepts concerning points on a line and lines through a point. Then the geometry of plane and space, leading up to conics and quadrics, is developed inside the triple frame of metric, affine, and projective transformations. The algebraic treatment is occasionally exchanged for the synthetic one. At many places the connection of the geometric material of the text with other fields is indicated, notably with axiomatics, algebra, descriptive geometry, vector analysis topology, and statics. Further developments serve the purpose of allowing the student to find his way in the literature.

MECHANICS

Mechanics. Stefan Banach. Translated by E. J. Scott. (Monografie Matematyczne, Vol. 24.) Warsaw, Monografie Matematyczne; New York, Hafner Publishing Company, 1951. 546 pp., figs. Cloth $9.50; Paper $7.50.

This text is limited to the mechanics of a system of material points and a rigid body. The mathematical prerequisites for reading this book are limited to the elements of analytic geometry and differential and integral calculus. Typical chapter headings are: Theory of Vectors, Kinematics of a Point, Dynamics of a Material Point, Systems of Material Points. In the Appendix is given a method of solving ordinary differential equations of the second order with constant coefficients.

NAVIGATION

ANDB Annual Report Fiscal Year 1952. Washington, Air Navigation Development Board, 1953. 7 pp.

A summary of 1952 operations including data on new projects and the current program and a list of technical and project reports.

PERSONNEL

Proceedings of the Second Conference on Scientific Manpower. 119th Meeting of the American Association for the Advancement of Science, held at St. Louis, December, 1952. Washington, National Science Foundation, 1953. 47 pp.

Contents: Supply of Scientific Manpower, Dael Wolfle. A Program of Research on the Characteristics of Scientists, E. G. Williamson. Implications for Higher Education, C. W. de Kiewiet. The National Science Foundation's Graduate Fellowship Program, Bowen C. Dees. Research Training in the Sciences, Warren C. Johnson. Plans for Registers and Clearinghouse Activities, Philip N. Powers. National Scientific Manpower Policy, Robert C. Goodwin.

The Research Approach to the Study of Human Resources. Pittsburgh, American Institute for Research, 1953. 12 pp., illus.

An introduction to the functions of the American Institute for Research, a nonprofit organiza-

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tion devoted to the systematic study of human behavior through a coordinated program of scientific research.

PILOTING

Pilot's Handbook. Hollywood 28, Calif., 5864 Hollywood Blvd. Pilot's Handbook, 1953. 66 pp., illus. $2.50.

A compilation of CAR air traffic rules, GCA unit locations, hand and light signals, radio and beacon codes, general radio information, meteorological data, and atmospheric and temperature tables. One quarter of the book consists of blank pages for recording flight data.

PRODUCTION

Heavy Press Program for Light Metals. Technical Papers and Discussions on the Air Force Heavy Press Program, New York, December 2, 1952. New York, American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers, Institute of the Aeronautical Sciences, and Society of Automotive Engineers, 1953. 158 pp., illus.

Technical papers presented and reprinted in this volume are: Paper No. 52-A-75—Requirements for Large, Light Metal Forgings and Extrusions in the Aircraft Industry, G. W. Papen. Paper No. 52-A-76—The Design and Construction of Large Forging and Extrusion Pressed for Light Metals, M. D. Stone. Paper No. 52-A-77—Metallurgy and Production of Suitable Aluminum Alloy Ingots for Large Forgings and Extrusions, T. L. Fritzlen. Paper No. 52-A-78—Large Forging Press Operations and Production Problems, G. W. Motherwell, J. R. Douslin, and A. L. Rustay. Paper No. 52-A-79—Large Extrusion Press Operation and Production Problems, T. F. McCormick.

Discussion and written comments are included.

Riveting Alcoa Aluminum. Pittsburgh, Aluminum Company of America, 1953. 90 pp., illus. diagrs.

Information on riveting aluminum, strength and proportions of riveted joints, driving methods, and alloy selection.

Casting Alcoa Alloys. Pittsburgh, Aluminum Company of America, 1953. 143 pp., illus., diagrs.

Descriptions of various aluminum casting alloys; considerations in selection of casting process; general foundry principles and precautions.

RESEARCH

Review of Current Research and Directory of Member Institutions, 1953. State College, Pa., Engineering College Research Council, American Society for Engineering Education, 1953. 330 pp. $2.50.

This fourth biennial review lists over 7,500 research projects in 103 institutions, in which over 13,000 persons are engaged. All branches of engineering and most related fields are covered. In addition to a subject index to research projects, this reference work gives names of responsible administrative officers, policies that govern research projects and contracts, personnel engaged in research activities, annual expenditures for research projects, sources of income for research, and special conferences and short courses of interest to research workers.

Proceedings of the Research Symposium on Physical Sciences and Engineering Held on April 24 and 25, 1953. State College, Miss., Mississippi State College, 1953. 140 pp.

Contents: Physics and National Prosperity, A. E. Ruark. Progress in Forest Utilization, G. A. Garratt. Industrial Chemical Research, Frank J. Soday. Role of Applied Mathematics in Research, F. O. Ringleb. Today's Miracles; Tomorrow's Necessities—Through Electrical Engineering, H. N. Muller. Building Solid Foundations, Paul E. Klopsteg. Structural Engineering Looks Ahead Through Research, Mace H. Bell. Mechanical Engineering in Research, Kenneth R. Daniel. Commercial Aviation Hampered by War, Grover Loening.

Annual Report, 1952, of the Armour Research Foundation of Illinois Institute of Technology. Chicago, 1953. 59 pp., illus.

Includes descriptions of research projects under way or completed during the year.

STANDARDS

Standards—Engineering Tools for Industry. Proceedings of the Third National Standardization Conference Combined with the Principal Addresses at the 34th Annual Meeting Award Luncheon, November 25, 1952. New York, American Standards Association, 1953. 64 pp.

Contents: Europe Discovers America, William L. Batt. Remarks upon Acceptance of The Standards Medal, Frank O. Hoagland. A Progress Report on Notable Standards Activities, Roger E. Gay. Standards—Engineering Tools for Industry, Joseph W. Barker. Standards for World Trade—An Opportunity for American Leadership, Cyril Ainsworth. Standards—A Procurement Tool, E. H. Weaver. A New Approach to Cost Reduction in the Building Industry, Willard T. Chevalier. The Engineering Significance of Standards—How Standards for Safety Can Help Reduce Insurance Premiums and Improve Industrial Relations, Donald G. Vaughan. What Standards Have Meant in the Economic Utilization of Our Products, Hampton M. Auld. How the Photographic Industry Developed National Standards, Paul Arnold. The Standardization Program of the American Welding Society, S. A. Greenberg. The Standardization Program of the Diesel Engine Manufacturers Association, Harvey T. Hill. The Chemical Industry's Approach to Procurement Standards—The Industry's Position, Granville M. Read. The Supplier's Position, Frank S. G. Williams. The Chemical Industry Correlating Committee's Position, J. G. Henderson. The ASME Boiler Code Committee and Its Work, Arthur M. Greene, Jr.

THERMODYNAMICS

Heat Transfer; A Symposium Held at the University of Michigan During the Summer of 1952. Ann Arbor, Mich., University of Michigan Press, 1953. 296 pp., illus. $5.00.

Contents: Conditions in Heat Transfer Problems Which Create High Thermal Stress, Alan S. Foust, Head, Department of Chemical Engineering, Lehigh University. Behavior of Materials Under Conditions of Thermal Stress, S. S. Manson, Chief, Materials and Stresses Branch, Lewis Flight Propulsion Laboratory, N.A.C.A. Liquid-Metal Heat Transfer, H. F. Poppendiek, Section Chief, Oak Ridge National Laboratory. Heat Transfer with Evaporation, Warren M. Rohsenow, Associate Professor of Mechanical Engineering, M.I.T. Recent Developments in Convective Heat Transfer with Special Reference to High-Temperature Combustion Chambers, Martin Summerfield, Professor of Jet Propulsion, Princeton University. Convective Heat Transfer at High Velocities, E. R. G. Eckert, Professor of Mechanical Engineering, University of Minnesota. Transpiration and Film Cooling, Professor of Mechanical Engineering, University of Minnesota. Forced Convection from Nonisothermal Surfaces, Myron Tribus, Director of Icing Research, and John Klein, Applied Mathematician, Engineering Research Institute, University of Michigan. Theoretical Considerations in Rarefied-Gas Dynamics, S. A. Schaaf, Associate Professor of Engineering Science, University of California. Comparison of Temperatures in Solid Bodies and Their Scaled Models, R. V. Churchill, Professor of Mathematics, University of Michigan.

YEARBOOKS

The Aircraft Yearbook, 1952. Official Publication of the Aircraft Industries Association of America, Inc. Washington, Lincoln Press, Inc., 1953. 464 pp., illus., diagrs. $6.00.

This edition, following the pattern of earlier years, contains reviews of activities in aviation companies, military aviation, governmental agencies, the light-plane field, and design and production. There are chapters describing and illustrating current aircraft and engines and giving official aviation records, chronology, and brief biographies of aviation personalities.

Changes of Address

Since the Post Office Department does not as a rule forward magazines to forwarding addresses, it is important that the Institute be notified of changes in address 30 days in advance of publishing date to ensure receipt of every issue of the *Journal* and *Review*.

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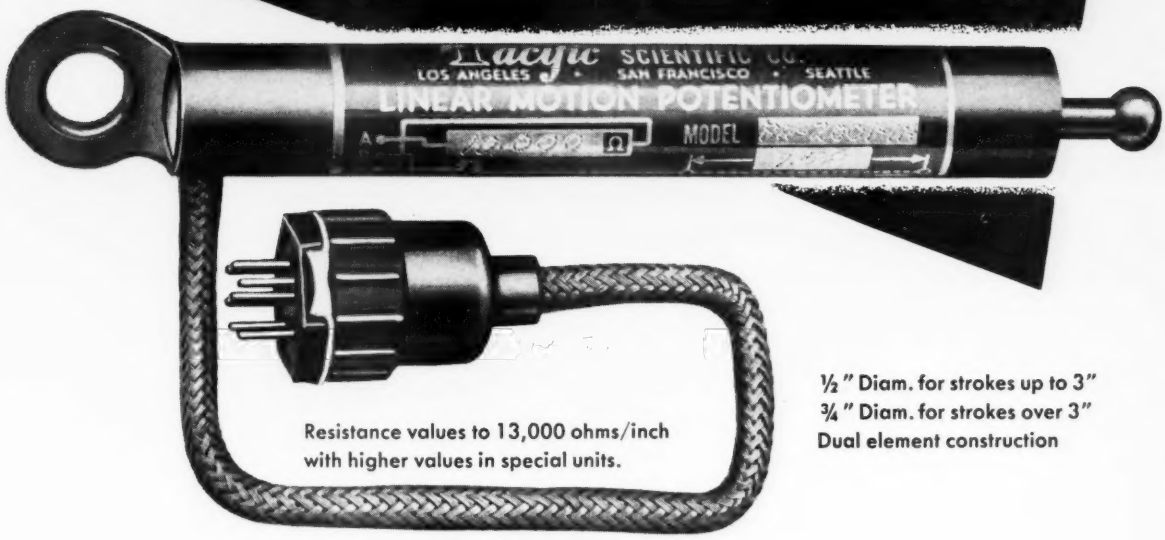

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Professor or Associate—The Brazilian Aeronautical Technical Institute needs high-grade professors specialized in aerodynamics, structures, and airplane design for further development of undergraduate and graduate courses and of laboratories. Prefer men with Ph.D. and teaching experience, but will consider applications from men with sound theoretical training plus practical experience. Salary and rank dependent on qualifications. Unusual opportunity for the right persons. Inquiries should be sent to Professor A. J. Meyer, ITA, COCTA, São José dos Campos, São Paulo, Brazil. Please include detailed information about education, experience, contributions, etc.

Aeronautical Engineer—Preferably with M.S. degree, to teach aeronautical engineering course, provide aeronautical consulting services, develop through theory and experiment new test methods in the field of flight testing, is needed by the Test Pilot Training Division of the Naval Air Test Center at Patuxent River, Md. Civil Service rating GS-9 to GS-11. Send résumé or Form 57 to Dr. W. J. Hesse.

Engineer—The Naval Air Missile Test Center, Point Mugu, Calif., has an opening for an aeronautical or general engineer, GS-12, $7,040 per annum. Description: Engineer in charge of Stress Group to perform structural analysis of aircraft modification, aircraft installations, missile components, and mechanical mechanisms and installations. Applicants should submit Standard Form 57, Application for Federal Employment (available at any Post Office), to the Commanding Officer (43), U.S. Naval Air Station, U.S. Naval Air Missile Test Center, Point Mugu, Port Hueneme, Calif.

Engineers—Opportunities for employment exist in the Bureau of Aeronautics, Department of the Navy, Washington, D.C. **Aeronautical Power-Plant Research Engineer**—GS-12, $7,040 per annum. Development of general designs and studies of reciprocating, turbojet, turboprop, ram- and pulse-jet, and rocket engines to be used in subsonic and supersonic land- and carrier-based aircraft and guided missiles. Requirements: 3½ years of professional engineering experience in addition to degree. **Mechanical Engineer**—GS-12, $7,040 per annum. Responsible for conducting investigations, studies, and projects in gas dynamics. Serves as expert, specialist, and consultant on gas dynamics for the purpose of guiding the development of new naval aircraft power plants. Plans, initiates, and supervises research, design, development, and tests of landing aides. Participates in review and evaluation of design studies made by contractors. Prepares test, installation, performance, and detailed specifications for landing aids and systems. Requirements: 3½ years of professional engineering experience in addition to degree. **Electronic Engineer (Radio)**—GS-12, $7,040 per annum. Interprets present and future military requirements for antisubmarine air-borne radar systems. Analyzes existing fleet equipment of this type to determine what improvements can be made to improve its efficiency for meeting operational requirements. Coordinates the research and development programs with other interested services, bureaus, and agencies. Requirements: 3½ years of professional engineering experience in addition to degree. **Aircraft Stability Control Engineer**—GS-12, $7,040 per annum. Plans, initiates, and coordinates guided-missile flight research and flight research and flight evaluation programs. Directs and carries out evaluations of the stability and control characteristics of proposed new guided missiles. Prepares specifications pertaining to aerodynamics analyses, especially stability and control of guided missiles. Requirements: 3½ years of professional engineering experience in addition to degree. **Aeronautical Development Engineer (Hydrodynamics)**—GS-11, $5,940 per annum. Under general supervision performs highly specialized aeronautical engineering work in the field of hydrodynamics in connection with design of naval aircraft: assists in model and full-scale, research and development projects in hydrodynamics for improvement of seaplane operation. Requirements: 2½ years of professional engineering experience in addition to degree. **Natural Gas Engineer**—GS-11, $5,940 per annum. Devising or examining and approving containers for the storage and transportation of helium. Experience in pressurization and compression systems; knowledge of methods and devices for controlling gases under pressure. Requirements: 2½ years of professional engineering experience in addition to degree. **Mechanical Engineer**—GS-9, $5,060 per annum. Prepares studies and layouts of test facilities for experimental and operational catapults and associated equipment for development of new systems and improvement of existing equipment; prepares preliminary analytical studies of catapulting systems and associated components for launching piloted aircraft to determine theoretical performance characteristics, strength requirements, and optimum configuration. Requirements: 1¼ years of professional engineering experience in addition to degree. **Mechanical Engineer**—GS-9, $5,060 per annum. Prepares preliminary studies to determine the theoretical performance characteristics, strength requirements and configuration of experimental catapults and associated components. Evaluates design proposals submitted by contractors and Government activities in connection with catapulting equipment to determine conformance with accepted engineering practice. Requirements: 1¼ years of professional engineering experience in addition to degree. **Aircraft Structural Development Engineer**—GS-9, $5,060 per annum. Critical review and analysis of contractor stress calculations consisting of detailed analytical determination of stress tolerances for specific load, carrying structural members. Specification of usable materials for contractor design. Requirements: 1¼ years of professional engineering experience in addition to degree. Applications may be submitted on Standard Form 57, Application for Federal Employment, to the Department of the Navy, Bureau of Aeronautics, Personnel Division, Attention: PE-202, Washington 25, D.C. The Standard Form 57 is available at U.S. Post Offices or may be obtained by writing to the Personnel Division, Bureau of Aeronautics. Visitors to the Washington area may call at Room 3909 of the Main Navy Building, 19th and Constitution Ave., N.W., Washington, D.C.

Engineers, Technologists, Physicists, Physiologists, Metallurgists—The Navy Air Material Center located in the U.S. Naval Base at the extreme south end of Broad Street in Philadelphia, Pa., has vacancies in the above positions for qualified eligibles. These vacancies are at grade GS-5 to GS-12 level with salary ranging from $3,410 to $7,040 per annum. The Naval Air Material Center (the Air Center is divided into three major branches: the Naval Aircraft Factory, the Naval Air Experimental Station, and the Naval Auxiliary Air Station) is engaged in research (applied), development, manufacture, modification, test evaluation, and overhaul of aircraft, aircraft components, and aeronautical materials, including launching and arresting devices. This activity has the job of finding the answers to a never-ending series of problems involving the whole field of aeronautical sciences. Interested persons should file an Application for Federal Employment, Standard Form 57, with the Industrial Relations Department, Naval Air Material Center, Naval Base, Philadelphia 12, Pa. Applications may be obtained from the Industrial Relations Department, Naval Air Material Center, or at any first- or second-class Post Office or from any Civil Service Regional Office.

502. Dynamics Engineer—Expanding New England firm of research engineers has several offerings for aeronautical or mechanical engineers with experience in dynamics. Projects include dynamic analyses of complicated structures subject to transient inputs, vibration analyses, aeroelasticity studies, laboratory vibration testing, and flight testing. Excellent opportunity for advancement with this young organization.

500. Associate or Assistant Professor of Aeronautical Engineering—Opening available for immediate appointment by state university in eastern United States. Applicant should be qualified to teach undergraduate and graduate courses in aerodynamics and related work, including compressible flow theory. Advanced de-

The number preceding the notices represents the Box Number of the Institute of the Aeronautical Sciences to which inquiries should be addressed.

gree required. Opportunity for combined teaching and research program. Enclose résumé of education and experience in initial reply.

499. Engineers—The following positions are available at a large East Coast engine manufacturer. **Process Engineer**—Responsible for establishment of methods by which experimental parts are to be manufactured. **Operation Sheet Writer, Senior**—To prepare operation sheets for any machining or assembly work through all steps to completion and to make estimates of tooling requirements. **Design Engineer, Senior**—To execute a variety of complex mechanical layouts of various components, of reciprocating and gas-turbine engines, with related heat transfer and also stress and thermal calculations. **Analyst, Senior**—Responsible for actual execution of any advanced research or analysis projects in particular technical or scientific field (chemistry, metallography, stress analysis, etc.). **Operation Sheet Writer**—Prepare operation sheets and machine routings for machining of assembly work where difficult or unusual operations are not required. **Layout Draftsman, Senior**—Responsible for execution of complex layout drafting assignments involving basic design for assembly, strength, and operation. **Tool Designer, Senior**—To design and draft a wide variety of tooling including jigs, fixtures, dies, and gages for use in machining and assembling parts or assemblies. **Design Engineer**—Responsible for execution of design projects covering engine assemblies or complex parts. **Test Engineer, Senior**—To execute advanced technical assignments relative to the planning and execution of experimental and development test programs. **Tool Designer**—To design and draft tooling such as jigs, fixtures, dies, and gages where there are no problems of unusual or difficult designs. **Test Engineer**—To execute fairly complicated technical assignments relative to the planning and execution of experimental or development test programs. **Test Engineer, Junior**—To execute fairly simple technical assignments relative to the planning and execution of various development test programs. **Design Analytical Engineer, Junior**—To perform less complicated theoretical analysis of engineering problems relative to the design of products. **Tool Designer, Junior**—To design and draft simple tooling, working from rough sketches or instructions supplied by Chief, Tool Design Unit.

498. Operations Research Man—With technical and economic background for interesting and varied and independent work on defense studies. Advanced degrees desirable. At least 3 years' industrial or operational experience required. Location, Washington, D.C., area.

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517. Aeronautical Engineer—B.Aero.E. Engaged 10 years in wind-tunnel research at high subsonic and transonic speeds. Active in problems of stability and control, wing-performance, wing-fuselage interference, propeller aerodynamics, and propeller vibrations. Experience also in the design and testing of wind-tunnel fans. Has completed course work in graduate training program leading to master's degree. Desires position in research and development or supervisory position connected with research and development. Preferable location east of Illinois and north of Virginia.

516. Engineering Pilot—B.S.Ae.E., 1942. Age 35. Eighteen years' flying experience. Air-line transport pilot rating, single- and multi-engine land CAA instrument and flight instructor ratings. Thirty-eight hundred hours flying time; 3,000 hours multiengine. One year part-time C.P.T. primary and secondary flight instructor. Three and one-half years' flight-test experience with manufacturer as experimental test pilot. Thorough engineering and flight background in aircraft performance, stability, controllability, and power-plant performance testing. Five years with air lines as air-line pilot, instrument and aircraft flight instructor, engineering and maintenance test pilot, and consulting engineer. Experience in both domestic and overseas air-line piloting on DC-3, DC-4, DC-6, and Constellation aircraft. Thorough working background in flight analysis with emphasis on aircraft performance as applied to CAA Transport Category. Has engaged in development of pilots' aircraft operating manuals and flight training manuals for aircraft manufacturer and air lines. Two years' experience in electronic and supersonic aircraft development work. Desires engineering pilot position with air line or manufacturer.

515. Structural Engineer—Bachelor of Aeronautical Engineering, 1946. Seven years' experience in aircraft stress analysis, including 1 year of static test at Wright Field as company representative. Desires stress analyst position. Résumé furnished upon request.

514. Aeronautical Engineer—Age 41. Degree of Aeronautical Engineer. Twenty years' experience in various phases of engineering. Thirteen years of aircraft design, preliminary design, and USAF. Seven years guided missiles, electromechanical design, and research in electronic air-borne equipment. Of experience noted, 12 years have been at the design supervision level. Desires position as staff engineer, consultant, or group leader in preliminary design in aircraft field. Detailed professional history furnished on receipt of letter describing position.

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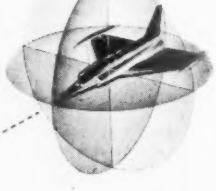

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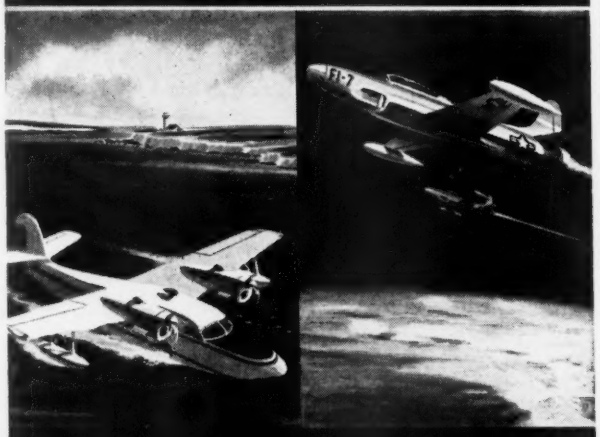

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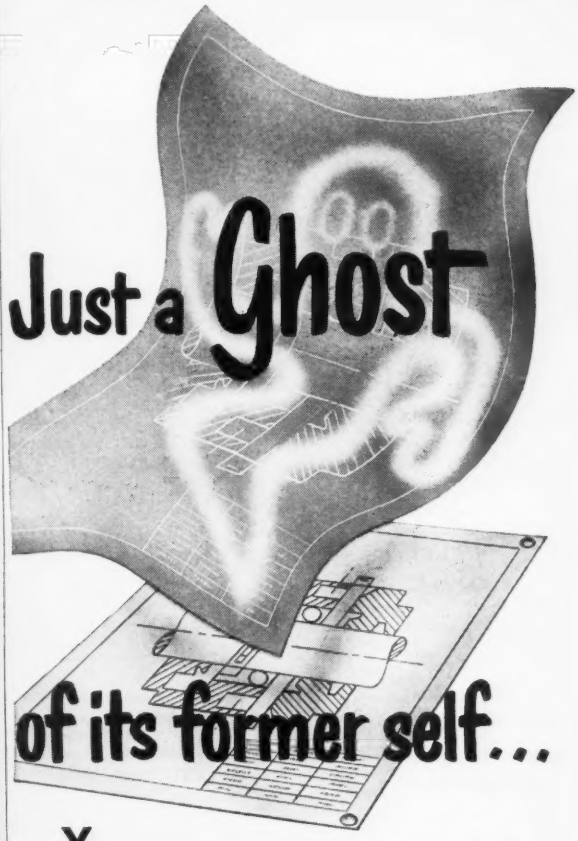

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513. Mechanical Engineer—Age 25. Broad experience in aviation including military and civilian pilot, 2,000 hours, single- and multi-engine, instrument and instructing experience. Heavy experience in 4-engined DC-4 transport aircraft. Qualified all phases of flight operations and control. Engineering experience in research and writing on propellers and propeller controls. Recent field service engineering experience in capacitance type fuel gages in combination with corporation pilot. Desires position with airframe, engine, instrument, or component manufacturer in flight test, operations or field engineering, or sales engineering.

512. Aeronautical Engineer—M.S. degree. Age 37. Fourteen years' experience in preliminary design, design aerodynamics, and structures of aircraft and guided missiles. Presently engaged as a supervisory design engineer in preliminary design analyses of guided missiles. Present salary in excess of $8,000. Desires responsible position in or related to aircraft or missile preliminary design or weapon-systems analysis.

511. Structural Engineer—Bachelor of Civil Engineering (magna cum laude) and Master of Applied Mechanics. Nine years' original research in elastic stability, plates and shells, aircraft stress analysis, sandwich theory, creep, and high-temperature problems. Supervisory and high-speed digital computing experience. Can be valuable as research engineer, stress analyst, structural consultant, applied mathematician, or teacher. Age 29.

510. Engineering Instructor—Ph.D. in applied mechanics (with background in A.E. & M.E.). Ten years' teaching and research experience in colleges. Currently engaged in structural research in aircraft industry. Desires a teaching and/or research position in college. Résumé furnished on request.

509. Aeronautical Engineer—B.A. and M.E. Age 48. Broad professional experience in aerodynamic research and development. Six years' teaching thermodynamics, aerodynamics, and structures. Would like position in school with E.C.P.D. accreditation or equivalent aim.

508. Aeronautical Engineer—Ph.D. in Applied Mechanics. Age 30. Six years' research experience in the field of hydro- and aerodynamics, elasticity, and structures. Desires a research and development position in the industry or research and/or teaching position in college. Salary open. Résumé furnished on request.

507. Professor of Aeronautics—B.S., M.S., and B.S.M.E. Registered Mechanical Engineer, State of California. Two years in guided missiles, 1 year responsible position as Branch Chief. Three years in industrial aircraft structures and mechanical equipment. One year as Professor of Aeronautics in structures. Four years as Associate Professor of Mechanical Engineering. Desires permanent position in university or supervisory and/or research position in guided missiles. Detailed résumé sent on request.

506. Aeronautical and Mechanical Engineer—M.S. in M.E.; Professional Engineer. Experience of 17½ years in turbojet, ram-jet, and rocket-propulsion systems and electronic instruments and controls design and development; helicopter and propeller design; automatic pilot developments and automatic heating and machine tool design and development. Thirteen years acting in a supervisory and administrative capacity. Over 3 years as project officer in Air Research and Development Command, Engineering Division. Has security clearance rating. Desires to utilize this experience as manufacturer's field or sales representative in New York and New England area.

505. Aeronautical Engineer—Ph.D. Age 29; 1 year's teaching and 2 years' industrial experience. Desires teaching position in college or university located in the East. Research opportunities preferred. Field of interest: aerodynamics and elasticity.

504. Advertising and Public Relations Manager—B.S. in Engineering/Business Administration, MBA in Marketing. Age 33, 10 years' progressive experience in all phases of industrial promotion: program planning, budgeting and administration, agency and media liaison, space and promotional copy planning, writing and editing, pamphlets and brochures, and technical publicity. Press, industry, and Government relations. Licensed pilot, mechanic, and radio operator with background in aviation equipment, radio and electronics and air transport. Desires position offering greater responsibilities and opportunity for advancement.

503. Engineer—Me., M.S. Ten years' experience in electromechanical and servodynamics fields. Presently head of Development and Research Section for manufacturer of servomotors, gyros, and avionic systems. Desires administrative position in research and development.

501. Young Electronics Management Executive—B.S., M.S., Offers knowledge gained as Vice-President with experience in Government sales, contract administration, purchasing, production, and engineering in the fields of electronics, rocket-motor research, and guided missiles. Reorganization, planning, and financing experience; a searching and creative mind to generate and recognize ideas. Locate anywhere. Minimum salary $15,000 plus.

492. Aeronautical Engineer and Technical Writer—M.S. in General Engineering. Over 15 years' diversified general and aeronautical stress and writing experience. Desires teaching position. Prefers New England or California location.

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